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A STUDY OF THE

Disposal of Chemical Waste at Sea

Report of the Committee for Investigation of Waste Disposal

NATIONAL RESEARCH COUNCIL

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by

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and

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Fish and Wildlife Service,

U. S. Department of the Interior

NATIONAL ACADEMY OF SCIENCES—NATIONAL RESEARCH COUNCIL

WASHINGTON, D. C.

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PREFACE

The increasing concentration of population in the neighborhood of New York City has brought with it many conflicts of interest relative to the pollution of the adjoining waters. Among these, the pollution of the Raritan River and Raritan Bay by industrial wastes and domestic sewage, following the somewhat phenomenal growth of the Raritan River Valley as an industrial area, has led to active measures to improve conditions in these waters. These included an order restraining the National Lead Company from continuing to discharge certain wastes from its titanium plant at Sayreville, New Jersey, into the Raritan River. This Company thereupon proposed and prepared to carry out a plan to barge the material to sea.

After consultation with many interested agencies, including the U. S. Coast Guard, the Fish and Wildlife Service, and the Atlantic States Marine Fisheries Commission, the Company secured permission from the Captain of the Port of New York to discharge the waste in an area thirteen miles from Scotland Lightship and ten miles off the New Jersey coast. Meanwhile, serious opposition to the proposal developed on the part of the commercial and sport fishing interests of the region, who felt that the operations would seriously interfere with their activities.

In order that the facts be fully and impartially developed, the National Lead Company requested the National Research Council to sponsor an investigation of the operation and its consequences, and made the necessary funds available. The Council in turn contracted with the Fish and Wildlife Service and the Woods Hole Oceanographic Institution to conduct studies.

While the results of these studies bear directly on the operations of the National Lead Company, they have a wider interest, since they may be applied to similar operations in this region or elsewhere. At the present time sewage sludges are being discharged at sea in the offing of New York and are the subject of complaint by fishermen and others. It would be naive indeed to doubt that, in the future, pressures will arise to dispose of other industrial wastes offshore, and it is most important to know what consequences are to be expected and what regulations are required to best serve the public interest.

The investigations have involved phenomena of a complex character. The full treatment of these matters is reserved for presentation in appropriate scientific publications. The present report attempts to give the results of these technical studies in terms familiar to those interested in the practical aspects of the problems of pollution, the disposal of waste products, and their control.

In initiating these studies the Fish and Wildlife Service assumed responsibility for the survey of the sport fishing of the region, for the biological studies, and for the drift bottle program, while the Oceanographic Institution undertook the hydrographic and chemical studies. The results are so closely interrelated, however, that they are reported jointly. Those primarily responsible for the conduct of the investigations were Dr. W. F. Royce, Mr. J. B. Colton, and Mr. R. J. Buller for the Fish and Wildlife Service; and Dr. B. H. Ketchum, Dr. J. C. Ayers, and Dr. Wm. L. Ford for the Woods Hole Oceanographic Institution.

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I. THE SPORT FISHERY OF THE NEW YORK BIGHT

THE interests most likely to be adversely affected by waste disposal operations at sea are the commercial and sport fisheries, and the other recreational activities along the coast. The magnitude and value of the latter interest cannot be questioned in a region close to large urban populations. The operations of the commercial fisheries are well recorded, but the extent of the sport fisheries is not so well known. There has been little published data available on the value, location, and catch of the several species of fish, except for a recent report prepared by Westman and Bidwell which emphasized the value of this resource (**12**).

It has been believed by many that sport fishing is being forced farther and farther to sea because of the sewage and industrial wastes from the great metropolitan area which are being disposed of at sea. With the initiation of barging of industrial wastes to sea by the National Lead Company in the spring of 1948, most active opposition was voiced by representatives of the sports fishery, who considered that their interests were seriously endangered.

The Fish and Wildlife Service has surveyed the sport fisheries of the bight between New York and New Jersey during the years 1948 and 1949. The main objectives of the survey were: (1) to determine the value of the sport fishery to provide a basis for comparing it with the industries with which it conflicted; (2) to obtain data on fishing localities and seasons which could be used to determine the most appropriate regions for waste disposal, and thus reduce the area of conflict between the fishery and waste disposal; and (3) to bring together data on the abundance of fish in the catch which would enable the long-term effects of waste disposal on the fishery to be evaluated.

Briefly summarized, the results of the 1948 survey were as follows:[1]

1. The sport fishing industry of New Jersey and southwestern Long Island was estimated to comprise about a thousand vessels, representing a total value of fifteen million dollars in boats and equipment. The boats were of two principal types: party boats that sailed regularly, took all passengers who appeared at a fixed rate per person, and fished mostly for bottom species; and charter boats, which catered to parties at a fixed price per trip, and fished mostly for surface fish by trolling.

2. Charter boats were found to fish the entire New York Bight even beyond the submerged Hudson River Gorge, and as much as 50 miles from shore. The "Mud Hole", a loosely-applied name for the upper end of the gorge, was found to be an important charter boat fishing area, especially for tuna. Almost 100 percent of the party boat fishing was confined to within 20 miles of shore and chiefly to the west of the gorge, and was concentrated near wrecks, underwater rocks, shoals, etc. (Figure 1).

3. The 1948 sport fishing season extended from the latter part of April through December (Figure 2), depending upon the seasonal appearance of mackerel off the New Jersey coast. With the passing of the spring migration of mackerel, charter boats turned to little tuna (false albacore), bluefish, bonito, skipjack, and bluefin tuna fishing in season; and party boats shifted to bottom fishing for scup, sea bass, fluke, croaker, weakfish, etc.

4. An analysis of the 1948 catch-per-trip for several species was derived to be used for comparison with subsequent years. Limited comparisons, however, were made with earlier years. The charter boat catch-per-trip of tuna during 1948 was not greatly different from the catch-per-trip in 1938 and 1941. The party boat catch-per-trip of scup and sea bass was found to be greater than that recorded in 1938.

Insufficient data were collected during the

[1] For a detailed report see Buller and Spear (**3**).

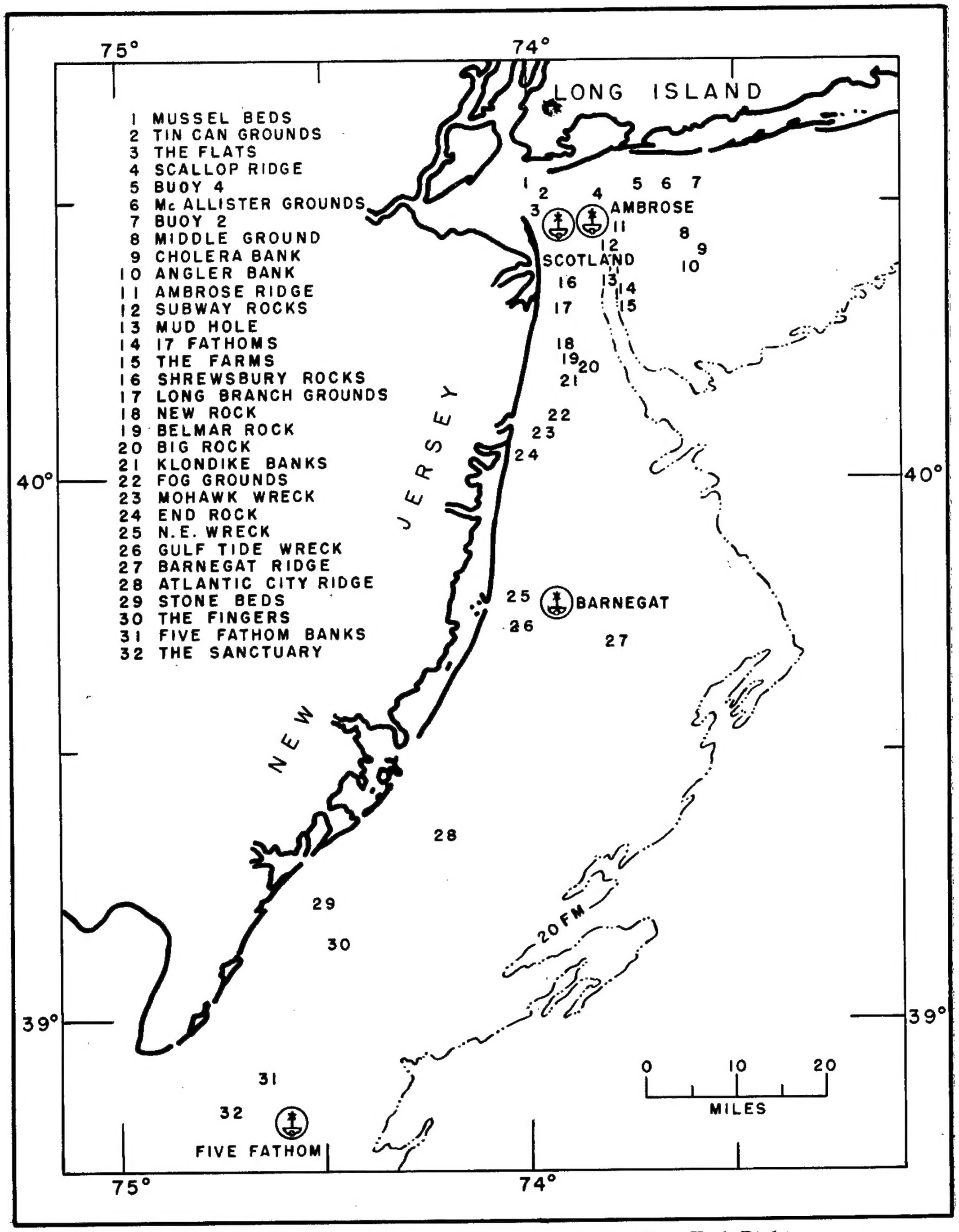


Figure 1. The named bottom fishing areas in the New York Bight

1948 survey to provide an estimate of the total sport fishery catch. The 1949 program was designed to furnish additional information on the value of the sport fishery, and on fishing localities and seasons; and to provide a means of estimating the total 1949 catch made by New York and New Jersey charter and party boats.

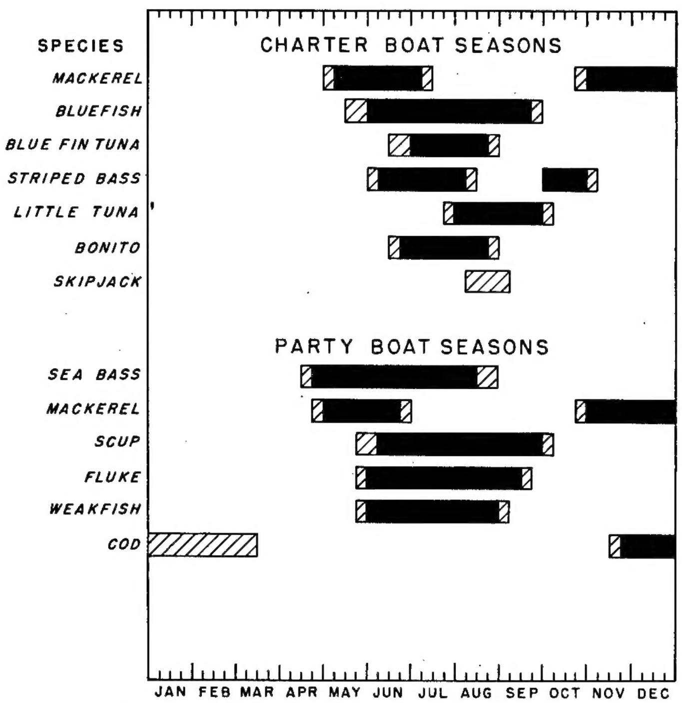


Figure 2. Sport fishing seasons in 1948 by species and boat type. Solid bar indicates catches of more than one fish per man per trip.

TABLE 1

NUMBERS OF CHARTER AND PARTY BOATS, BY PORTS, ENGAGED IN THE 1949 COMMERCIAL SPORTS FISHERY

Ports	Charter Boats	Party Boats
NEW YORK		
Freeport	66	11
East Rockaway	10	10
Sheepshead Bay	9	51
Other ports west of Freeport	14	17
NEW JERSEY		
Elizabethport to Highlands	7	13
Highlands	28	5
Belmar	11	13
Brielle and Point Pleasant	147	37
Forked River	36	2
Barnegat City to Atlantic City	62	
Atlantic City	18	22
Ocean City to Wildwood	11	23
Wildwood	2	43
Cape May	12	44
Total	433	291

To obtain these data, an investigator was in the field continuously from April 20 to the middle of November, 1949, and occasionally after that. He visited routinely all of the fishing ports from Freeport, Long Island, to Cape May, New Jersey. Each port was visited once each two weeks, and the time spent there was proportional to the size of the fleet at the port.

The fleet at these ports (Table 1) comprised 724 vessels, of which 433 were charter boats and 291 were party boats. This number is somewhat less than the number estimated to be engaged in the fishery in 1948. When the private pleasure craft of the charter boat class join the hired craft during the height of the fishing season, however, the number of sport fishing vessels in the New York Bight may exceed 1,000 vessels.

Of this fleet, only the vessels fishing out of the ports from Freeport, Long Island, to Brielle and Point Pleasant, New Jersey, were found to fish in the vicinity of the area now

assigned to waste disposal operations out of New York Harbor. From the interviews with captains of the vessels landing at these ports the region was divided into areas five minutes of latitude and longitude on a side, or about five miles by four miles in size. The

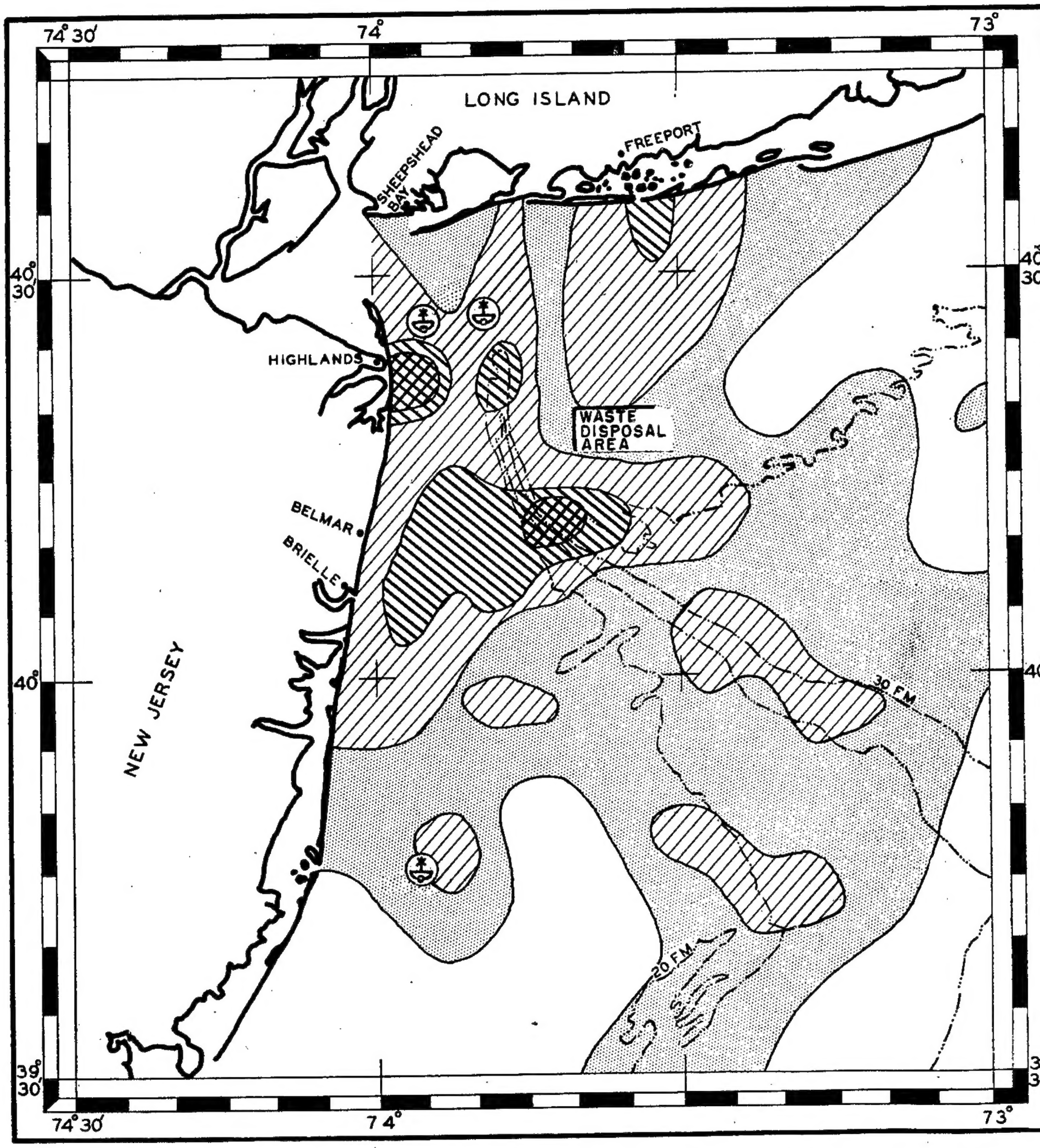


Figure 3. Localities fished by the charter boats sailing from Freeport to Brielle and Point Pleasant in 1949. The stippled areas represent less than 100 trips per 20 square miles per year, right-oblique-lined areas 100 to 500 trips, left-oblique-lined areas 500 to 1,000 trips, and cross-hatched areas more than 1,000 trips.

during the 1949 season it was possible to estimate and plot the charter boat (surface trolling) fishing pressure for different areas of the New York Bight. For this purpose number of fishing trips to each area during the year was used to indicate the fishing pressure. While the charter boats ranged far at sea at times, the areas subjected to the

greatest fishing pressure (more than 1,000 trips per 20 square miles per year) were

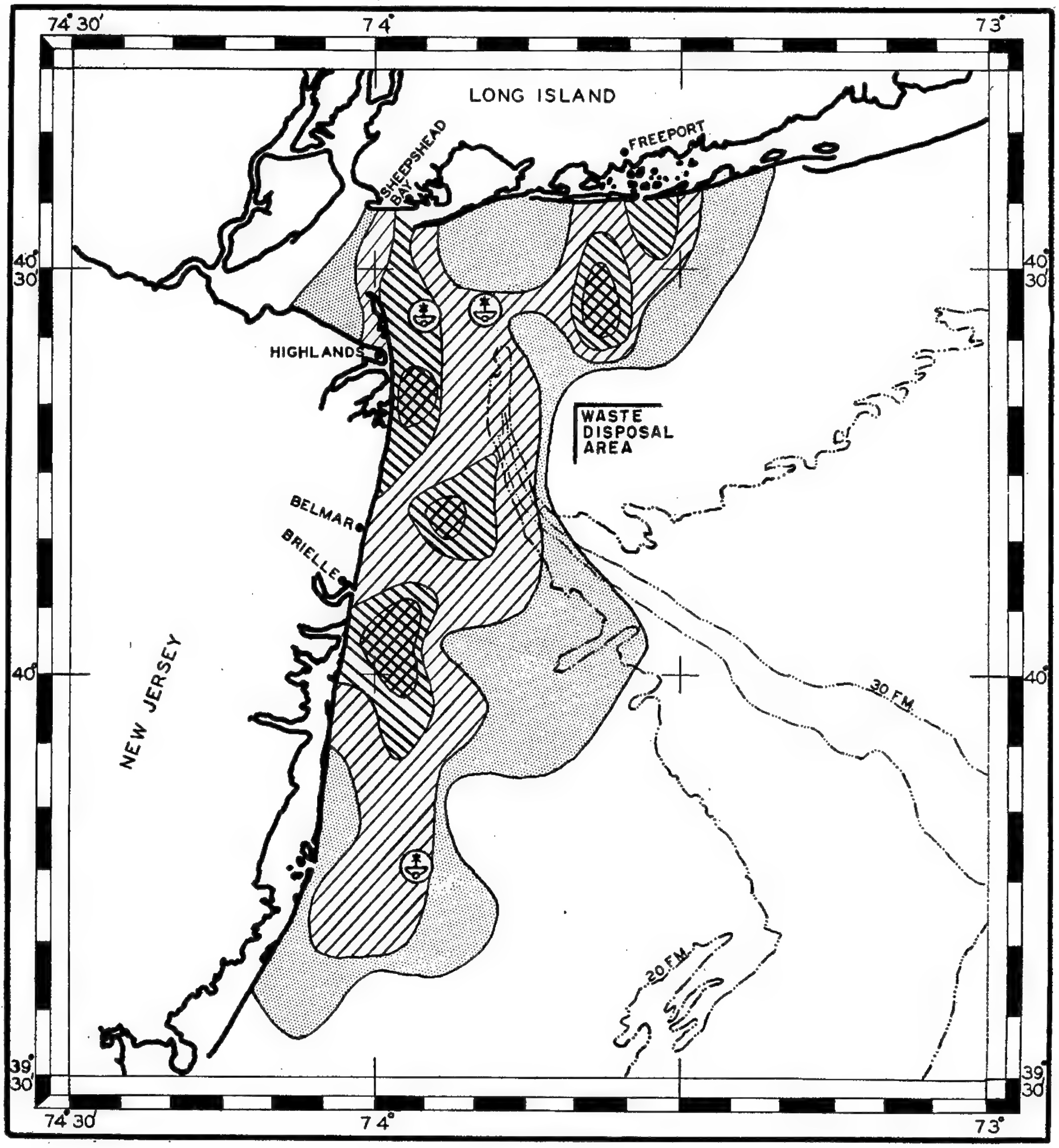


Figure 4. Localities fished by the party boats sailing from Freeport to Brielle and Point Pleasant in 1949. The stippled areas represent less than 100 trips per 20 square miles per year, right-oblique-lined areas 100 to 500 trips, left-oblique-lined areas 500 to 1,000 trips, and cross-hatched areas more than 1,000 trips.

in the vicinity of Shrewsbury Rocks and about 20 miles east of Brielle (Figure 3). The "Mud Hole" area south of Ambrose Lightship and a small localized area off Jones inlet, Long Island, received from 500 to 1,000 trips during the 1949 season. The remainder of the inner bight shows a fishing pressure of 100 to 500 trips, or less than 100 trips per 20 square miles per year.

Party boats, fishing on the bottom, ranged at sea less (Figure 4), but, like the charter boat fishery, the Shrewsbury Rocks area

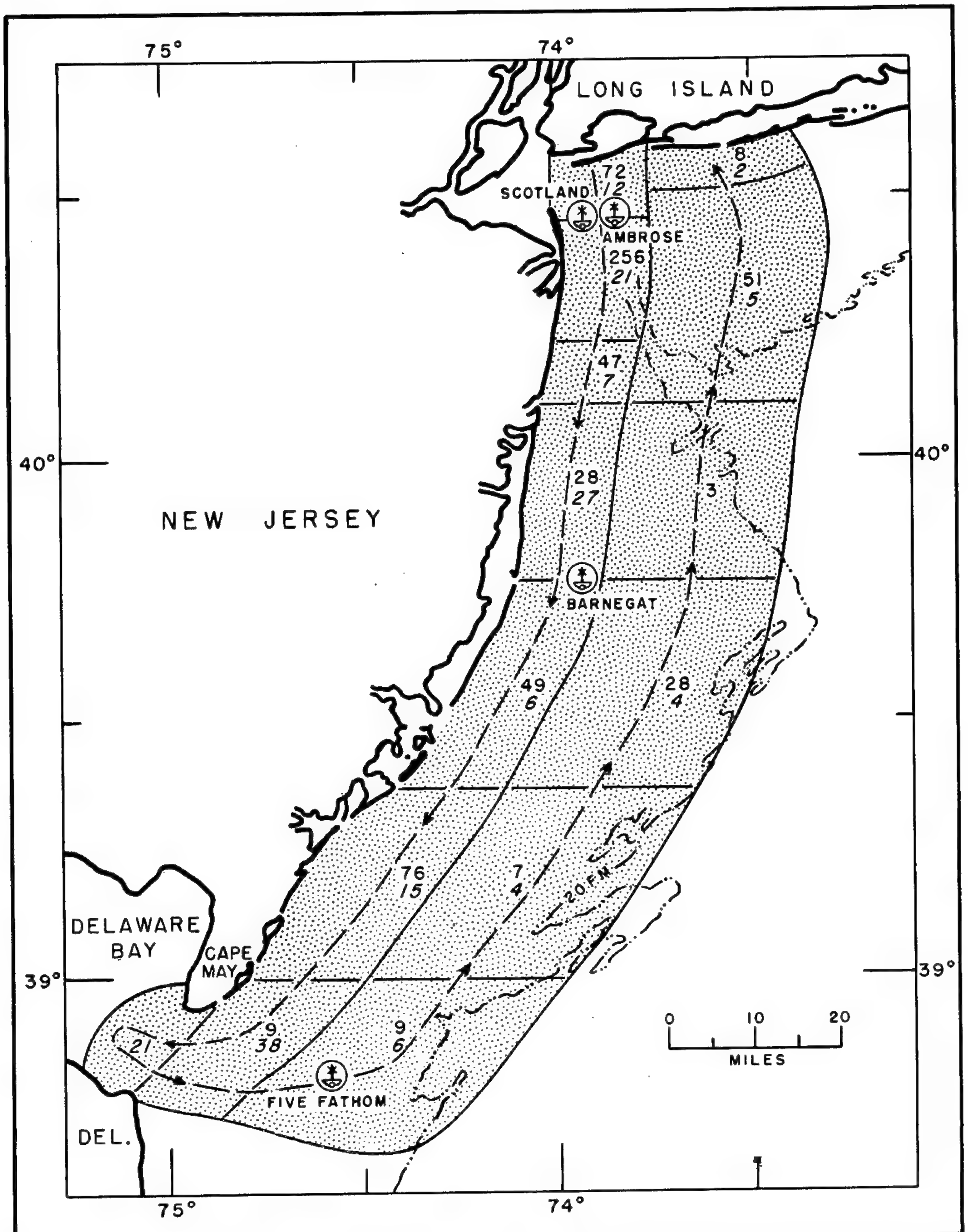


Figure 5. Numbers and locations of charter boats (vertical figures) and party boats (slanted figures) observed by airplane on Labor Day, September 3, 1949.

received a fishing pressure of more than 1,000 trips per 20 square miles per year. Other areas subjected to this intensity included Cholera Bank, the Klondike-Big Rock area east of Belmar, and a concentration of wrecks some 5 to 15 miles southeast of

Brielle. Party boats, like charter boats, made from 500 to 1,000 trips to the grounds off Jones Inlet. Another area receiving a comparable fishing pressure extended from Rockaway Inlet to just north of Belmar. This area includes the Tin Can Grounds, the Flats, the Mussel Beds, and the various wrecks and rock grounds in the vicinity of Shrewsbury Rocks.

five miles offshore and the second about twenty miles offshore (Figure 5). On this flight the observer counted a total of 737 vessels; 596 charter boats and 141 party boats. Visibility during the flight varied from 5 to 10 miles on either side of the plane and it is believed that only a small percentage of the sport fishing vessels "out" that day escaped detection.

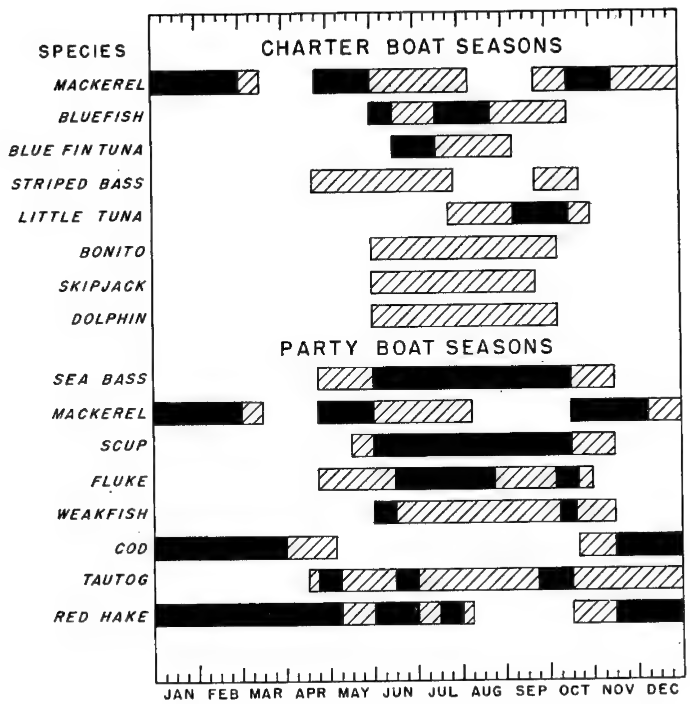


Figure 6. Sport fishing seasons in 1949 by species and boat type. Solid bar indicates catches of more than one fish per man per trip.

Further data on the numbers of fishing vessels and the location of fishing grounds were obtained by flying over the area. Three flights were made in a PBY plane through the cooperation of the United States Coast Guard at Floyd Bennett Field. The first and second flights, made in July and August respectively, were unsuccessful because of fog and haze which obscured the observer's vision. The third flight, made on Labor Day (September 3) covered the bight from Long Island to the entrance of Delaware Bay in two long sweeps—the first approximately

The concentrations of charter and party boats illustrated in Figure 5 closely parallel the fishing charts (Figures 3 and 4). The greatest concentration of sportfishing vessels was observed in the vicinity of the lightships and along the New Jersey coast. The number of charter boats observed during the flight exceeded the total number of this class of vessel considered to be engaged in the commercial sport fishery. This excess was no doubt due to private pleasure craft which could not be distinguished from charter boats from the air.

Data were also collected on the duration of the charter and party boat fishing seasons during 1949 (Figure 6). Both fisheries enjoyed a season for mackerel during the winter of 1948–1949 which was somewhat longer than usual. As a rule, fishing for mackerel begins to wane the latter part of November. For some reason—perhaps the open winter and abundant food supplies—mackerel remained in the New York Bight throughout the early part of 1949, with good mackerel fishing to be had until the first part of March, after which they apparently migrated out of the bight area to return about six weeks later. In general, the major portion of the 1949 sport fishing season occurred from May through September, but some fishing was pursued throughout the entire year.

TABLE 2

COMPARISON OF THE ABUNDANCE OF PREDOMINANT SPECIES IN THE COMMERCIAL SPORT FISHERY IN 1948 AND 1949

Species	1948		1949	
	Fish per Trip	Fish per Fisherman	Fish per Trip	Fish per Fisherman
CHARTER BOATS				
Mackerel	153.5	25.1	309.4	33.0
Bluefish	30.1	5.7	33.3	6.0
Little tuna	12.1	2.3	18.6	3.6
Bluefin tuna	7.5	1.1	23.3	4.2
PARTY BOATS				
Mackerel	586.1	30.0	540.0	26.0
Scup	310.5	19.8	722.0	32.2
Sea bass	160.5	12.9	329.0	17.0
Weakfish	141.5	19.1	190.1	18.5
Fluke	53.3	11.6	122.6	7.6

The abundance of predominant species in the charter and party boat catch during the major portion of the 1949 sport fishing season is compared to the abundance of these species during the 1948 season in Table 2. These figures show that the charter boat catch of mackerel, bluefish, little tuna, and bluefin tuna per trip and per fisherman was greater than the catch in 1948. The greatest increase is noted in the catch of bluefin tuna. This species, mostly small "school" tuna, were three times as abundant in 1949 as in 1948. Scup were about twice as abundant in 1949 and sea bass showed a small increase. Mackerel and weakfish were about the same as in 1948, whereas fluke showed an increase in the catch per trip; but with more people being carried the catch per fisherman decreased.

TABLE 3

ESTIMATED COMMERCIAL SPORT FISH CATCH LANDED BETWEEN FREEPORT, LONG ISLAND, AND POINT PLEASANT, NEW JERSEY, DURING 1949

Species	Estimated Catch (Thousands of Fish)		
	Party Boats	Charter Boats	Total
Scup	3,161	126	3,287
Mackerel	1,985	1,047	3,032
Sea bass	1,032	73	1,105
Red hake	208	4	212
Fluke	186	24	210
Tautog	146	6	152
Bluefish	4	136	140
Weakfish	78	15	93
Cod	66	12	78
Little tuna	1	46	47
Bluefin tuna		24	24
Dolphin	2	12	14
Skipjack		6	6
Bonito		3	3
Striped bass		1	1
Miscellaneous	74	27	101
Total	6,943	1,562	8,505

An estimate of the sport fish catch from the bight which was landed by vessels from Freeport, Long Island, to Point Pleasant, New Jersey, is presented in Table 3. The total estimate of 8,505,000 fish landed includes both the charter and party boat catch but does not include the catch made by private pleasure craft.

SUMMARY

THE general conclusions which may be reached from the survey of the sport fishery are:

1. The sport fishery employs about 1000 boats representing an estimated investment of fifteen million dollars. Since the 300 party boats carry an average of 20 fishermen and 700 charter boats and private craft about 7, it is evident that many thousands of persons benefit from the recreation of sport fishing. The sport fishing industry consequently has a strong claim for protection from possible harmful effects of waste disposal.

2. While the area of intense fishing is concentrated for the most part within fifteen miles of the Long Island and New Jersey coasts, charter boats fish widely over an area extending nearly 50 miles from the coasts. There appears to be no accessible area which might be assigned for waste disposal which would be entirely outside the regions sometimes visited by fishermen. While the greater part of the fishing is conducted in May through September, some fishing is pursued throughout the entire year.

3. The abundance of predominant species of fish was greater in 1949 than in 1948 or 1938. Fish populations are subject to such marked fluctuations in abundance from year to year that this fact cannot be taken to indicate any long-term trend.

II. THE BEHAVIOR OF WASTE UPON DISCHARGE INTO THE SEA

BECAUSE OF the large volumes of waste involved in the National Lead Company's operations, and the presence in it of a familiar acid, it was only natural that those to whom the full facts were not available should entertain alarming conjectures. It was feared that masses of undiluted acid would drift about upon the sea's surface or would settle to the bottom where fishes would be injured. It was rumored, even before the barging operations began, that fishing nets were being rotted by the discharged acid. While it could be predicted in advance that these extreme fears were groundless, one could not be at all sure just how the waste would behave on discharge, how rapidly it would be dispersed, and at what depths it would be found. Consequently, the first matter to be investigated was the behavior of the waste upon discharge into the sea.[2]

1. THE BARGING OPERATION

THE WASTE originates at the titanium plant of the National Lead Company at Sayreville, New Jersey, near the mouth of the Raritan River. It is held temporarily in storage tanks until it can be removed by the barge. The barge, constructed for the purpose (**10**), carries 3,200 tons of the waste, and when operating on full schedule discharges one load every 18 hours (Figure 7). The barge is towed by a tug at a speed of approximately six knots, the waste being discharged from two twelve-inch pipes mounted on skegs at keel level at the after end (Figure 8). When the barge is fully loaded, these pipes are at a depth of 15 feet, but as the waste is discharged the depth decreases to six feet when the tanks are empty. About eighteen tons of waste are discharged per minute. This gives a rate of discharge of about sixty pounds per foot of distance traveled.

The discharge pipes are so located that the waste enters the sea in the very turbulent region where water displaced by the barge's passage is rushing in under the stern to form the wake. It is consequently mixed rapidly with the water of the wake and greatly diluted.

Initially, an area two miles square centered ten miles SE × E from Scotland Lightship was assigned for this purpose. This area is immediately over the submerged gorge of the Hudson River, where depths up to thirty-two fathoms (192 feet) occur. While discharging waste the barge circled within this area.

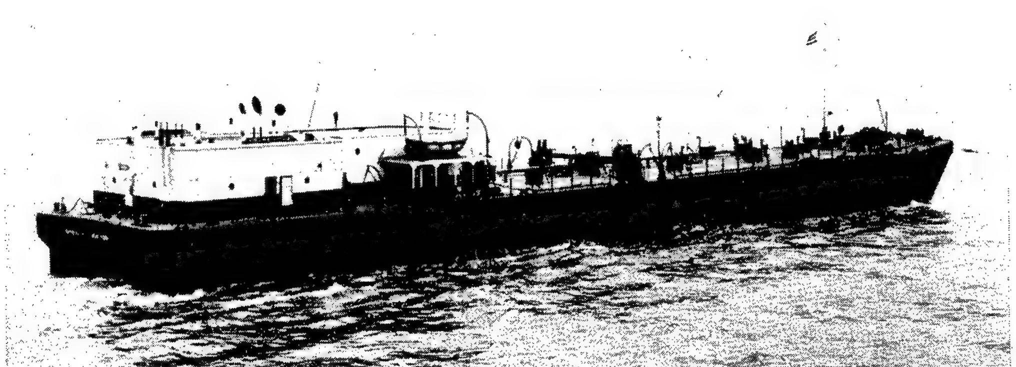
At the request of the New York State Department of Conservation, a new area for disposal was assigned in April 1949. This area was located at a greater distance from the more important fishing grounds. The barge was required to remain south of the parallel 40°20′N latitude and east of the meridian 73°40′W longitude. The point of intersection of these limits is 13 miles SE from Scotland Lightship, 14 miles from the New Jersey coast and 15 miles from the Long Island coast. The depth in this area is about eighty feet. While discharging the barge usually proceeds in a southeasterly direction for a distance of five or six miles and then turns to return over a parallel course. This arrangement provides for an initial dispersal of the waste material over a wide area.

The location of the waste disposal areas is shown on the chart reproduced in Figure 9.

2. THE NATURE OF THE WASTE AND ITS REACTIONS WITH SEA WATER

THE WASTE consists of approximately ten percent ferrous sulfate ($FeSO_4$) and 8.5 percent sulfuric acid (H_2SO_4) dissolved in fresh water. Many other substances are doubtless present, but not in quantities likely to prove harmful. The expected chemical effects on the sea water will be those arising from (1)

[2] For a detailed report see Ketchum and Ford (**8**).



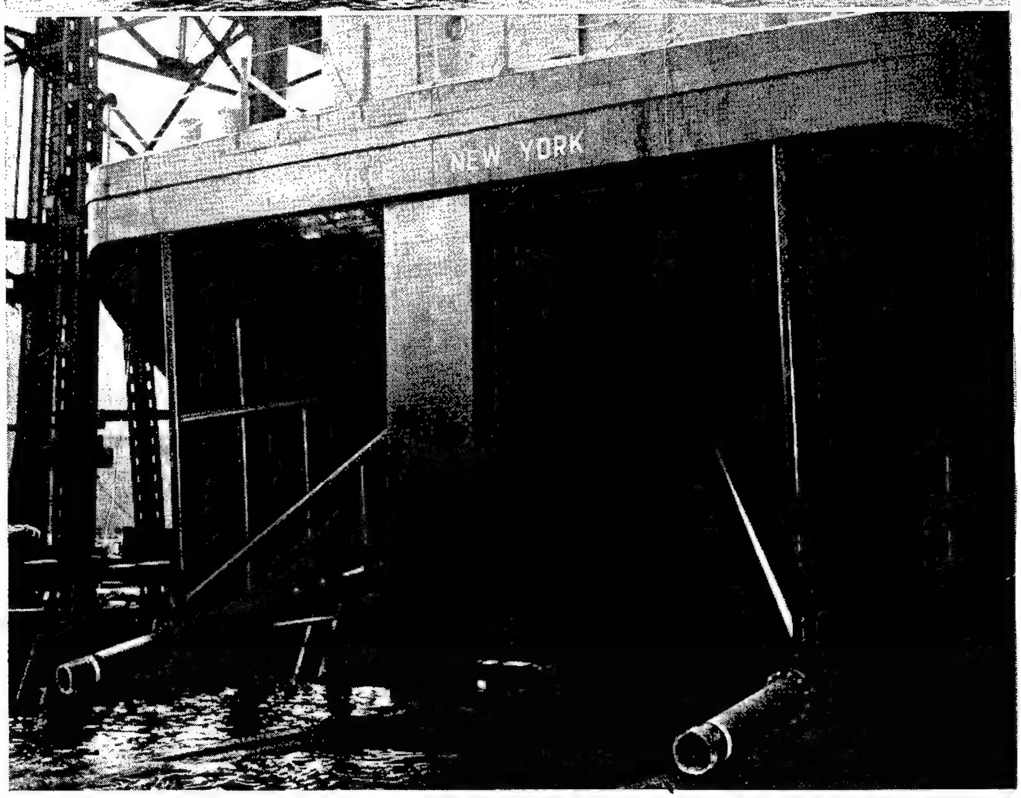


Figure 7 (upper). Barge *Sayreville* constructed for the disposal of titanium waste at sea. (Courtesy of National Lead Company.)

Figure 8 (lower). Stern of the barge *Sayreville*, showing the position of the pipes through which waste is discharged. (Courtesy of National Lead Company.)

an increase in the ferrous ion concentration, (2) an increase in the sulfate ion concentration, and (3) disturbance in the acid–base balance of sea water because of the acidity of the waste material.

The most immediate effect of the addition of ferrous ion to sea water will be to reduce the oxygen content of the water, since the ferrous ion will be rapidly oxidized. The resulting ferric ion will be precipitated as

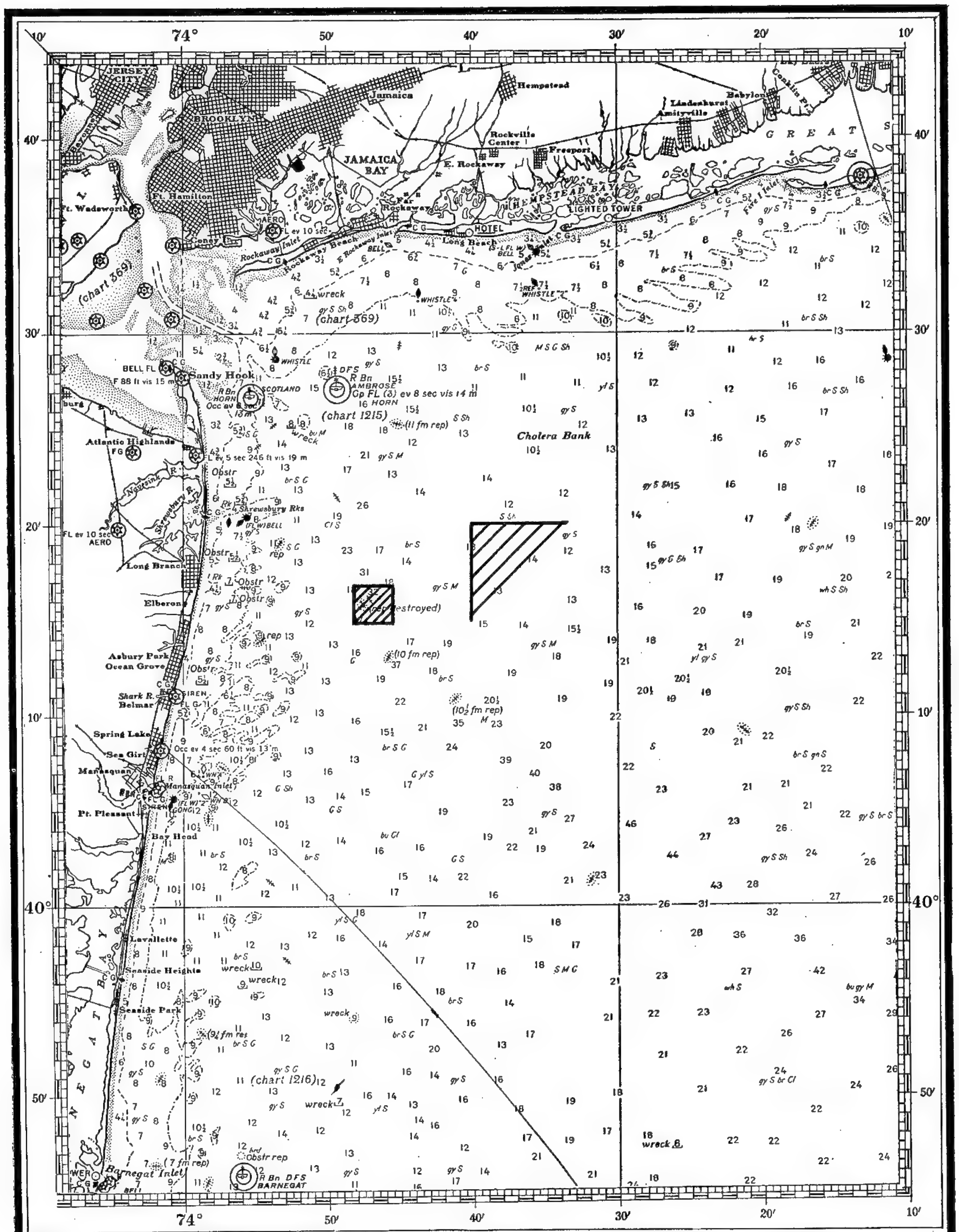


Figure 9. Chart of the New York Bight. The area presently assigned for waste disposal is shown as a triangle. The original area, shown as a square, is no longer in use. Based on U. S. Coast and Geodetic Survey Chart No. 1108. The numbers on the chart show depths in fathoms.

ferric hydroxide, since sea water is saturated with respect to ferric ion. The product will be an inert material which forms colloidal suspensions and may be expected to settle

slowly and thus become widely dispersed by currents.

The sulfate ion is itself one of the principal normal constituents of sea water, being present in concentrations of 2.65 parts per thousand. Unless it were added to sea water in quantities which would seriously upset the salt balance, it is not likely to produce toxic or other undesirable effects. There is no possibility that such effects could be produced by the quantities of waste in question.

The disturbance of the acid–base balance of sea water by the addition of the waste might produce degrees of acidity which would be distasteful or harmful to marine life. Sea water is a weak alkaline solution having normally a pH of 8.0 to 8.2. Its ability to neutralize acids is well understood, and it was possible to estimate in advance that the waste would not only be greatly diluted on introduction into the wake but also that it would be rapidly neutralized upon mixing with sea water.

For example, if the initial dimensions of the wake are given by the beam of the barge (43 feet), by its mean draft (10.5 feet), and by the rate of advance (6 knots or 600 feet per minute), the volume of wake water with which the waste mixes is 270,000 cubic feet, or 15,600,000 pounds per minute. If the waste is discharged at the rate of 18 tons or 36,000 pounds per minute, the waste will be diluted at once in the proportions 36,000:15,600,000, or about two parts to one thousand. The dilution of sulfuric acid present at 10 percent in the waste becomes two parts in ten thousand.

The ability of sea water to neutralize acids depends upon the fact that it contains a certain amount of base combined as bicarbonate. This fraction of the total base is known as *excess base*. On addition of an acid, such as sulfuric, the excess base combines with the sulfate ions to form sulfates, setting free an equivalent quantity of carbonic acid. This is a weak acid which, when the reaction is complete, does not reduce the pH below about 4.5. Furthermore, the carbonic acid can rapidly escape as carbon dioxide from the sea surface, which permits the sea water to return to neutrality.

The excess base present in sea water (of salinity 32 such as occurs in the coastal water off New York) is 2.16 milliequivalents per liter. This means that there is sufficient base present in ten thousand parts of sea water to combine with one part of sulfuric acid. Until this ratio is exceeded there will not be any free sulfuric acid present and the pH will not fall below 4.5. Comparing this proportion with the estimated dilution of the waste in the wake (two parts in ten thousand) it is evident that under the assumed conditions about half the sulfuric acid will be neutralized immediately on mixing with sea water at the stern of the barge. Furthermore, since the wake mixes rapidly with the surrounding water, as evidenced by its tendency to widen as it falls astern, the remaining sulfuric acid will be neutralized within a short distance behind the barge.

These considerations made it appear unlikely that any serious degree of acidity would exist, except briefly, in the water into which the waste was discharged. While the chemistry on which they are based is well established, no information exists concerning the actual way in which the waste would behave on discharge from a moving barge, or on the details of the mixing processes which would take place in the wake after the barge's passage. Consequently, a detailed examination was made of the chemical conditions in the water left astern by the barge while waste was being discharged.

3. OBSERVATIONS ON THE DILUTION AND NEUTRALIZATION OF WASTE IN THE WAKE

To CONDUCT this study the Woods Hole Oceanographic Institution employed its research vessel *Balanus*, a 76-foot fishing vessel converted for research purposes. She is small enough to maneuver safely close to the barge and has sufficient speed to avoid being left behind during such operations. She is fully

equipped for hydrographic studies and for the special chemical observations required. (See Figure 10.)

Two sensitive chemical methods were available for measuring the waste in the sea water. The sulfuric acid could be detected by its effect on the pH of the water, which was measured by the usual meters. The *Balanus* was equipped with a recording pH meter which determines the acidity of a stream of sea water pumped through it from a sea cock located about four feet below

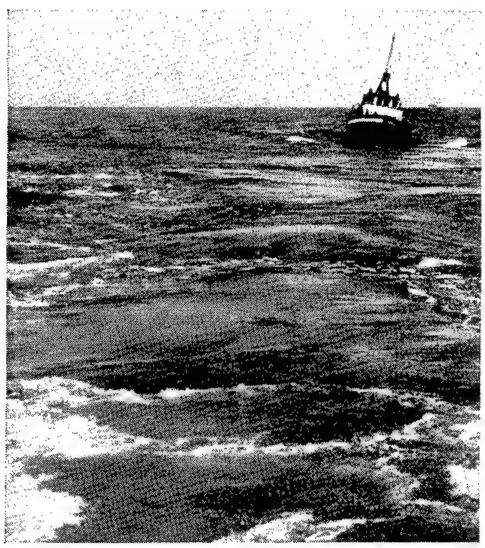


Figure 10. Research vessel *Balanus* investigating the concentrations of waste in the wake of the barge *Sayreville*.

the water line. Continuous information was thus available for the acidity at that depth. In addition, samples of water drawn from other depths could be measured with the usual laboratory model pH meter. A much more sensitive test for the presence of the waste material is provided by the iron present in it as ferrous sulfate. Iron can be detected by the dipyridyl method described by Cooper (**4**) in concentrations as low as one part in 100 million parts of sea water. This means that the presence of waste could be detected after dilution with three million parts of sea water.

The study of the wake required the exact sampling of the water at various depths and distances behind the barge. For this purpose, a newly-developed device known as the Sea Sampler was used (**11**). (See Figure 11.) This instrument consists of a number of small tubes or "bottles" through which water circulates freely as it is lowered over the side of the ship. As the Sea Sampler is brought to the surface again, the bottles are closed automatically at predetermined depths by the change in pressure. In this way, samples could be obtained from any part of the wake.

The investigation showed that the estimates of the immediate dilution of the waste in the wake were essentially correct. Samples collected as close to the point of discharge as possible and within thirty seconds after discharge were already diluted with sea water more than 250 times.

After the passage of the barge, the wake continues to mix with the undisturbed water on either side. In consequence, its visible width increases and the waste material in the wake water becomes more and more dilute until it is no longer recognizable. With dilution the acidity decreases rapidly, as shown by the rise in pH. These changes in the surface water are summarized in Table 4 and are illustrated in Figures 12 and 13.

Although the wake continues to grow in width for a long time as it spreads at the sea surface, it reaches its greatest depth almost immediately. During observations in April, 1948, the limiting depth of the wake was about thirty feet, while in July it was fifty feet. In January, 1950, the disposal area had been moved to a location where the total depth of water was 70–80 feet, and the waste was detected in water near the bottom at distances greater than 450 yards behind the barge. Figures 14 and 15 show measurements of the vertical distribution of pH and iron in the wake made during the April studies. It seems probable that these limits were set by the thermal stratification of the water which hinders vertical

mixing. In winter the wake may mix more deeply since stratification is weaker or absent, but during the spring and summer there is little likelihood that contaminated water of 25 yards, and has a depth of 12 yards. These are the dimensions of the entire volume which at any one time has an acid reaction. They represent a surface area of

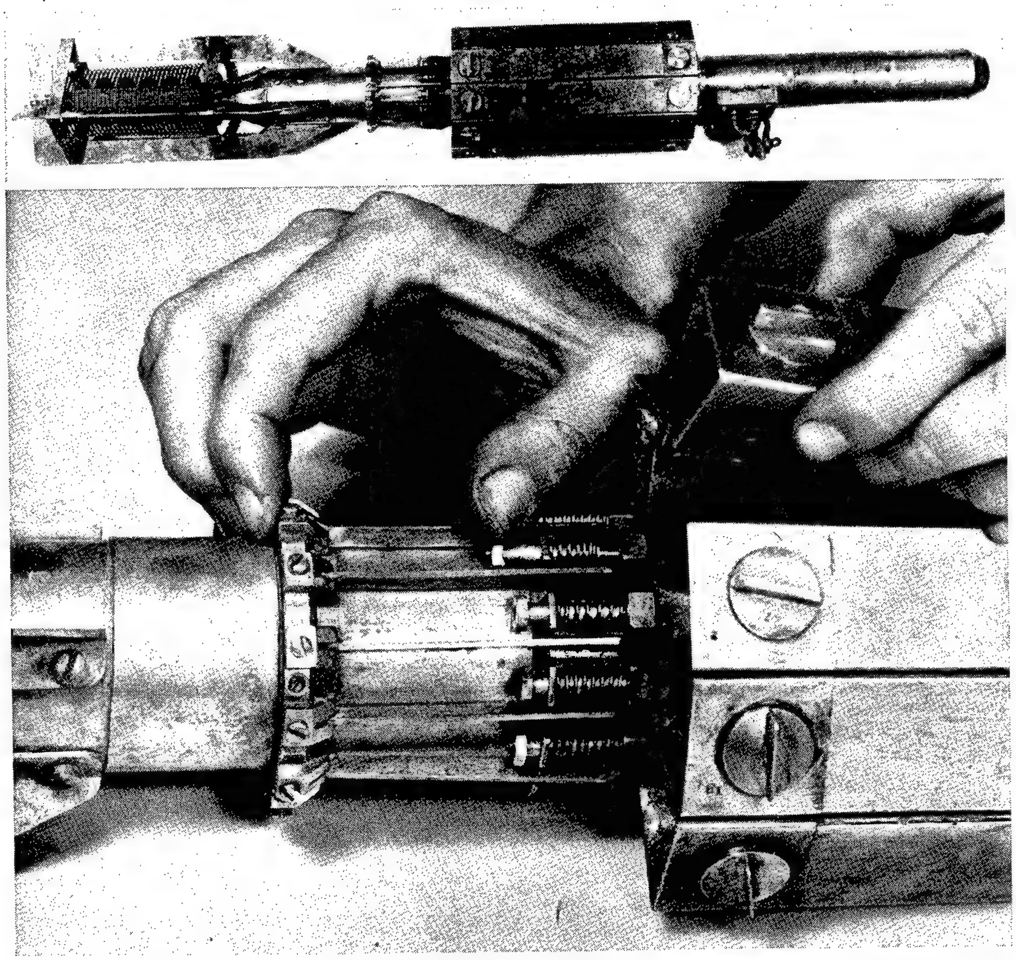


Figure 11. The Sea Sampler, a device employed for sampling water at various depths in the wake of the barge. The lower view shows a water sampling bottle being removed. (After Spilhaus and Miller (**11**).)

will reach the bottom in depths of sixty feet or more.

The important point brought out by these studies is the very rapid neutralization of the acid waste in the wake. Within three and one-half minutes after the passage of the barge, the water has returned to the neutral reaction of pH 7. In this time, the barge has moved 700 yards and the wake has spread from a width of 10 yards to one

TABLE 4

Visual Estimates of the Width of the Wake Behind the Barge

Age of Wake	Distance Astern of Barge	Visual Width of Wake
Minutes	*Yards*	*Feet*
8.5	1700	100
16.5	3300	225
20.5	4100	635
27.5	5500	750

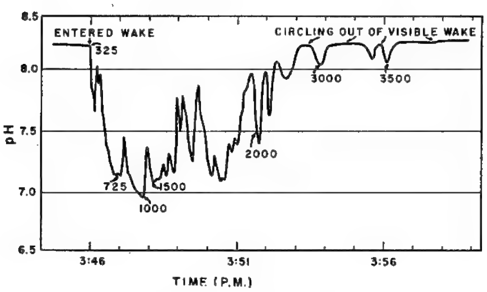


Figure 12. Tracing of pH record in the wake after passage of the barge *Sayreville*, while discharging waste. The numbers on the record are the distances behind the barge, in yards. (April 27, 1948.)

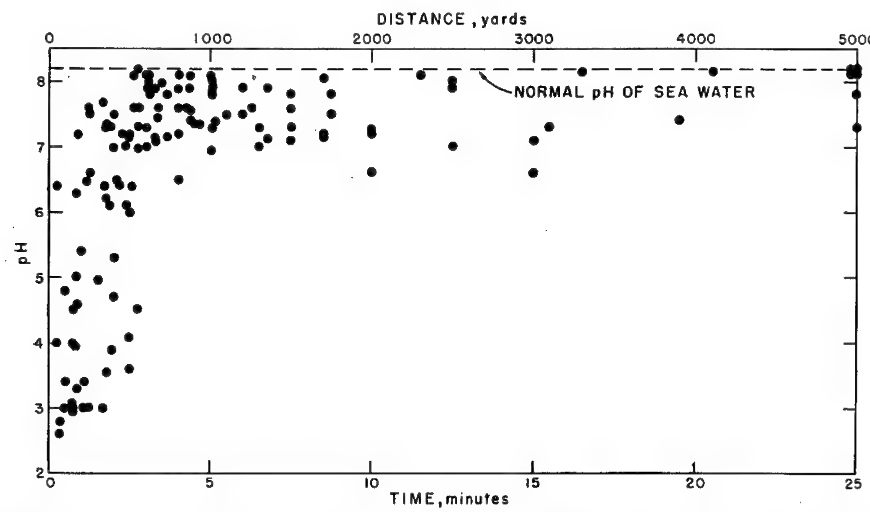


Figure 13. Values of the pH of the surface water in the wake of the barge measured at various times after the passage of the barge. Upper scale shows the distance traveled by the barge beyond the points of observation.

less than 3 acres. The entire area of the sea surface made acid temporarily by a single load of waste is about $\frac{1}{4}$ square mile.

The waste has a bright green color because of the ferrous sulfate present in it. Immediately behind the barge the water is discolored by the waste, which appears light green against the darker green of the sea water. Gradually the wake turns brown as the ferrous iron is oxidized and forms ferric hydroxide. The ferric hydroxide, which is nothing but finely divided iron rust, remains in suspension and gives the wake a muddy appearance which makes it prominently visible, especially in sunny weather. In such weather the discolored water is visible for at least three or four hours after discharge, and on one occasion a patch of water was recognizable by its color for about eight hours.

The oxidation of ferrous iron may be expected to use up a certain amount of the oxygen in the sea water. Since this might prove harmful, the rate of oxidation of the iron was carefully followed. The oxidation takes considerable time and is only half complete about forty minutes after discharge into the sea. At no time was enough ferric iron present in the water to have used up more than three or four percent of the oxygen present.[3] It was concluded that the oxidation of the iron has only a brief and negligible effect on the oxygen content of the water.

The ferric hydroxide itself is a quite inert substance not likely to have much effect on living organisms. In the high concentration in which it is produced immediately behind the barge, the precipitate is quite visible and may well influence the movements of fish, as might any other cause of dense turbidity. It is evident from the analysis of the distribution of iron in depth that it stays in suspension until greatly dispersed by mixing

[3] Technical details were reported by Ketchum and Ford (**8**).

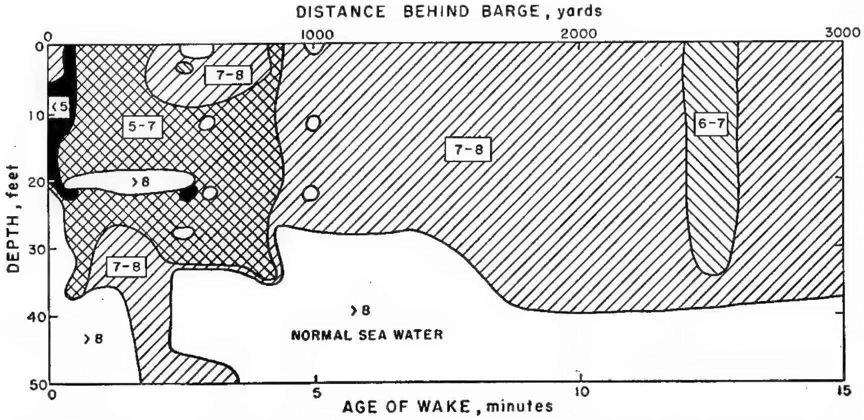


Figure 14. Distribution in depth of pH values of water in wake of the barge. April 1948

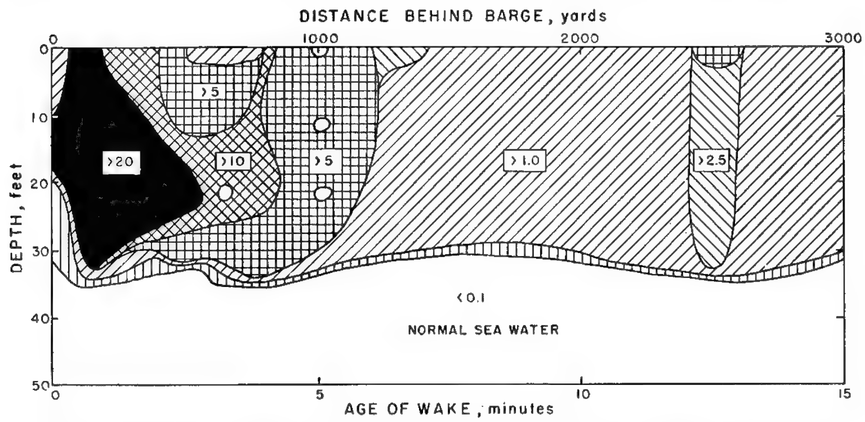


Figure 15. Distribution in depth of iron in wake of the barge. April 1948

with the surface water, and it must in consequence become distributed very widely before settling to the bottom.

It will be shown subsequently that the sea water in the approaches to New York Harbor is considerably contaminated with iron brought in by the rivers. Conditions in the wake of the barge during disposal operations can thus be compared with those actually occurring in various parts of the area. It is found that thirty minutes after the passage of the barge the waste has become so dispersed that its iron content is about the same as that which was observed in the head of Raritan Bay in July 1948. In four or five hours, the iron concentration in the wake is comparable to that in the sea in the neighborhood of Sandy Hook and Scotland Lightship.

SUMMARY

THE STUDY of the behavior of the waste in the wake of the barge during disposal operations indicates that the acidification of the sea water is very short-lived because of the rapidity with which the waste is diluted and neutralized upon discharge into the turbulent wake. Water which has been appreciably modified in its chemical properties is not likely to be found near the bottom or at any substantial distance from the barge and will exist nearby only immediately after its passage.

The only prominent after-effect of the disposal operation is the turbidity of the water due to the formation of ferric hydroxide in the wake.

III. THE BIOLOGICAL EFFECTS OF WASTE DISCHARGE

1. PHYTOPLANKTON

THE PRIMARY source of food for the animal life in the sea is the microscopic floating plants called phytoplankton. These organisms drift with the currents and multiply very rapidly if the water contains the necessary plant nutrients. Even if we assume that many of the phytoplankton exposed to acid in the wake would be destroyed, the volume of water acidified is so small compared to the area as a whole, and the phytoplankton multiply so rapidly, that the effect of such damage on the food supply would be negligible. Moreover, as will be shown subsequently, the water in this region of the coast is in such active circulation that new bodies of sea water are constantly replacing those into which the waste has been discharged.

Since iron is required in low concentrations for the growth of phytoplankton it has been suggested that the waste might actually improve the plant population. The studies have shown, however, that the waters in the offing of New York are unusually rich in iron as the result of the high content of the Hudson, Raritan and other rivers draining into the area. Once dispersed, the iron discharged by the barge would not greatly change the amounts available for growing plants.

2. ZOOPLANKTON

THE MINUTE marine animals which are dispersed through sea water, called zooplankton, are the immediate source of food of many fish. In order to test the effect of the wake water on these organisms, small samples of zooplankton were collected from uncontaminated water and were exposed to water drawn from the wake at various distances behind the barge. The results of this experiment are summarized in Table 5. Although the organisms in every case were immobilized by exposure to the wake water, they usually recovered their activity and appeared to be in a normal condition after two or three minutes even though they remained in the contaminated water. The specimens exposed to the most heavily contaminated water, which had been drawn from the wake less than one minute after passage of the barge, did not recover spontaneously. However, when the water containing these organisms was diluted with an equal volume of uncontaminated water, they recovered and commenced to swim about immediately.

Under the conditions of operation, in which the wake water is rapidly diluted after passage of the barge, some of the organisms drawn into the wake immediately behind the barge might suffer permanent damage. However, as in the case of the phytoplankton, the volume of water acidified by each barge load is very small compared to that in the disposal area, and the effect on the zooplankton population would be negligible, even though the organisms entrapped in the wake were destroyed.

3. THE BOTTOM POPULATION

WHEN the disposal operations at sea were first under consideration it was feared that the waste might settle on the bottom and would damage the bottom living organisms, and thus affect the ground fishery. It was consequently planned to study the conditions at and over the sea bottom by photographing the bottom and collecting the animals in the mud. Similar observations were made in the "Mud Hole" which was selected as a control area not immediately exposed to contamination.[4]

Observations were made in these two areas in March, 1948, before disposal operations had begun, and in May, 1948, when dumping had been in progress for about one

[4] These investigations have been reported in somewhat greater detail by Arnold and Royce (1).

month. These observations were lumped together as the best representation of "normal" conditions, since unexpected difficulties prevented an adequate representation from being obtained in March. Studies were again made in November, 1948, after disposal had been going on for seven months, in the hope of showing up any effects of the operation. Photographs of the bottom were made in representative areas, from which all recognizable animals and signs of life such as worm trails and burrows were screened to separate the animals, which were identified and counted. The results of these studies are summarized in Tables 6 and 7. They show that the numbers of organisms varied greatly, some increasing while others decreased during the period intervening. From the number of observations which were made, it is quite impossible to determine whether the changes are due to the natural changes which accompany the seasons, to inadequate sampling of bottoms which doubtless vary from place to place, or to any possible effect of the dumping of waste. At least it was clear that the populations changed in the control area in the Mud Hole quite as much as in the disposal area.

TABLE 5

EFFECT OF WASTE ON ZOOPLANKTON

Yards Behind Barge	Age of Wake	pH	Iron	Effect	Recovery Time	Condition at 5 Minutes
	Min.		*mg. per l.*		*Min.*	
145	0.7	5.65	26.0	Immobilized	Incomplete	Not normal
250	1.2	6.36	10.8	"	2–3	Normal
375	1.8	6.57	12.6	"	1	"
475	2.3	6.92	5.4	"	1	"
650	3.2	6.80	2.4	"	1–2	"
800	3.9	6.62	10.5	"	3	Nearly normal
1250	6.1	7.42	3.0	"	1	Normal
1520	7.5	6.95	2.2	"	1–2	"

TABLE 6

NUMBERS OF ANIMALS TAKEN IN BOTTOM SAMPLES WITH $9\frac{1}{4}$-INCH GRAB

	Disposal Area		Mud Hole	
	March & May	November	March & May	November
Sea Urchins	4	0	0	0
Sea Cucumbers	113	37	0	0
Flat Worms	2	0	0	4
Nematode Worms	0	0	0	1
Annelid Worms	301	331	26	46
Clams	72	12	12	126
Snails	2	0	0	0
Amphipods	17	168	0	0
Crabs	1	0	0	0
No. of Specimens	513	248	38	177
No. of Samples	37	13	8	12
Specimens per sample	14	19	4.8	14.6

TABLE 7

NUMBERS OF ANIMALS VISIBLE IN PHOTOGRAPHS OF THE SEA BOTTOM

	Disposal Area		Mud Hole	
	March & May	November	March & May	November
Sponges	0	0	1	0
Star Fish	37	34	1	1
Sea Urchins	2	0	6	1
Sea Cucumbers	0	1	0	0
Crabs	2	0	0	0
Animal Trails	10	0	0	1
Animal Burrows	25	14	15	0
No. of Specimens	76	49	23	3
Area Covered—sq. ft.	246	281	40	296
Specimens per sq. ft.	0.31	0.17	0.57	0.01

counted. Specimens were also taken from the bottom using an orange peel dredge $9\frac{1}{4}$ inches in diameter. These specimens were

One positive conclusion can be drawn, however, from this study. Large numbers of animals survived on the bottom of the disposal area after seven months of operation. The widespread annihilation of the bottom fauna which had been feared by some did not occur.

The change in the area assigned to dumping in the spring of 1949 prevented the continuation of these observations. Since it had become evident that a prohibitively large number of samples and photographs would need to be taken to obtain a reliable quantitative estimate of changes in the bottom population, and since the study of the behavior of the waste in the wake of the barge indicated that effects on the bottom population were unlikely, this phase of the investigation was discontinued.

4. FISH

THE pelagic fish, such as the mackerel and tuna which are valued highly by the sport fishermen, are active swimmers, fully able to avoid being drawn into the wake or swimming into regions where chemical conditions might prove harmful. Moreover, these are migratory species which move into the area from other parts of the ocean. Waste disposal operations cannot be expected to influence such fish by direct damage. They might exclude fish from the contaminated region if the food supply were to be destroyed, or the condition of the water sufficiently altered.

We have seen that there is little evidence that the food supply in the form of zooplankton will be reduced by waste disposal on its present scale. It is more difficult to obtain evidence on whether the fish will be repelled by the condition of the water. The most prominent effect of the contamination is the discoloration of the water resulting from the precipitation of ferric hydroxide in the wake of the barge. Patches of this precipitate have been observed eight hours after discharge. While the material is not toxic, it might well, like any other source of turbidity, be avoided by fish which are commonly inhabitants of very clear water. It will be shown in the following section that there is no evidence that the general turbidity of the waters off New York has increased during the period of 18 months of waste disposal off shore, and it may be concluded that the effects of turbidity from this source will be temporary and local.

TABLE 8

NUMBER OF FISH CAUGHT WITH OTTER TRAWL NET IN ACID DISPOSAL AREA

	Species	May 20, 1948		November 4, 1948
		Tow 1	Tow 2	Tow 1
1	Haddock*			140
2	Whiting	1	2	283
3	Hake, red	2	4	21
4	Hake, white	4	1	1
5	Blackback		4	2
6	Four spotted flounder			2
7	Mackerel		1	
8	Butterfish	6	4	5
9	Sea herring		28	
10	Alewives		48	
11	Shad			2
12	Weakfish			3
13	Sea bass		9	
14	Cunner	10	17	
15	Scup			6
16	Sea robin	1		
17	Filefish			1
18	Long horn sculpin			3
19	Goosefish	2		3
20	Lobster			1
21	Squid			68
	Totals	26	118	472

* All of the haddock were young of the year ranging in length from 4 to 7 inches.

Final evidence on whether the pelagic fish are being influenced by the waste disposal operations will probably be forthcoming only from the experience of the fishermen. The results of the survey of catches made during 1948 and 1949 at least give no indication that the first year of these operations was harmful to the fishery.

The fish which keep to the bottom are

also a shifting population which tends to congregate where food conditions are good. No evidence could be obtained that the invertebrate life, which forms the food supply of such fish, was seriously damaged in the disposal area during the first summer's operations. A few otter trawl hauls were made by the Fish and Wildlife Service's vessel *Albatross III* in the original disposal area in May and November, 1948, to see what fish might be found. The catches are summarized in Table 8. While the hauls were too limited to serve as a guide to changes in abundance, which in any case might be due merely to the season, they show clearly that ground fish were abundant even in November, after waste disposal had continued for seven months.

SUMMARY

THE biological observations have failed to produce any direct evidence that the populations of fish or of bottom living animals are being damaged or excluded from the area by the disposal of wastes. While zooplankton introduced directly into the contaminated water of the wake are temporarily immobilized they recover when this water is diluted with clean sea water, as would occur rapidly where organisms were caught in the wake. In view of the rapid dilution and neutralization of the waste in the wake, and the very small part of the sea water in the area which is temporarily acidified, it is not likely that the microscopic plants or animals forming the basic food supply of fishes are being significantly affected.

IV. EVIDENCE ON THE ACCUMULATION OF WASTES FOLLOWING PROLONGED BARGING OPERATIONS

THE WASTE from the Titanium Plant of the National Lead Company has been barged to sea continuously at a rate of about 4,000 tons per day since April, 1948. It is obviously important to determine whether this continued discharge is leading to the accumulation of pollutants in the water or on the sea bottom. Consequently, an extensive study of the chemistry of the sea water in the offing of New York Harbor was made before, and periodically since, the beginning of the disposal operations. These surveys covered an area extending south and east for twenty-five miles or more from the entrance to Lower Bay. In addition, studies have been made in Lower Bay, Raritan Bay, and Raritan River, which show the effects on those waters of deflecting the waste from the Raritan River. The dates and extent of these surveys are indicated in Table 9.

1. THE ACCUMULATION OF IRON IN THE SEA WATER

THE PROPERTY of the water most likely to show accumulative effects is the iron content, since this element is present in the waste in great amount, its product in sea water is stable, and it can be detected even at great dilution.

The iron has been measured by the dipyridyl method described by Cooper (**4**). Since the solubility of iron in sea water is very small, virtually all of the iron is present as a very finely divided precipitate. Consequently, the results of iron analyses tend to be erratic, because the suspended particles do not become uniformly distributed as materials in solution do (**5, 6, 7**).

The concentrations of iron found in the surface waters off New York are shown in Figure 16. In general, it may be said that the iron content of the offshore water does not exceed 20 parts per billion, except where the effect of the water emerging from Lower Bay is evident. At the mouth of Lower Bay and extending for some distance seaward, the iron concentration may be four or six times greater than off shore, i.e., 80 to 120 parts per billion. The surveys showed that high concentrations are associated with the water of low salinity emerging from Lower Bay and which spreads from there in a pattern which varies from time to time. The general pattern of circulation which determines the way in which the iron content is distributed will be discussed in the following section.

A summary of the iron content of the water as observed at various places in the Bays and outer approaches to New York Harbor before and after the beginning of barging operations is given in Table 10. In the waters of Raritan and New York Lower Bays, the iron content has decreased markedly during the period. This change will be discussed below. In the offshore area the data do not indicate any substantial change in concentrations which might be related to the disposal operation, although the quantities of iron vary considerably from time to time. The Shrewsbury Rock station has been included because it is the location of a popular fishing area. The iron concentrations at this station were generally greater than those observed either at the original disposal area or at Cholera Bank, just north of the present disposal area.

Additional information on the accumulation of iron is given by a comparison between the total quantity of iron within the area at any one time and the rate at which it is being introduced by river flow and barging. The study shows that iron is being contributed to the sea at a high rate by the rivers entering the area, whereas the quantity of iron actually present in the sea water within an area of some 600 square miles is

less than that coming in from the rivers within two weeks.

The contribution by the rivers may be estimated from the average concentration of iron in the river water multiplied by the volume of river flow. A somewhat analogous method has been developed for use in tidal systems, such as that which occurs at the mouth of Lower Bay, which utilizes knowledge of the net water transport across a section of the channel instead of the volume of river flow. The two methods give results in reasonably good agreement.

TABLE 9

List of Surveys and Special Studies

Date	Vessel	Object	Area Surveyed
			sq. mi.
Feb. 2–19, 1948	*Balanus*	Hydrographic Survey	
		New York Bight	483
Mar. 12–Apr. 4, 1948	*Balanus*	Hydrographic Survey	
		New York Bight	300
		Raritan & Lower Bay	83
		Photographic studies	
Apr. 20–30, 1948	*Balanus*	Hydrographic Survey	
		New York Bight	662
		Study of wake	
May 18, 1948	*Albatross III*	Photographic studies	
July 22–31, 1948	*Balanus*	Hydrographic Survey	
		New York Bight	684
		Raritan & Lower Bay	83
		Drift bottle releases	
		Study of wake	
Oct. 21–29, 1948	*Caryn*	Hydrographic Survey	
		New York Bight	468
		Drift bottle releases	
Nov. 1–2, 1948	*Albatross III*	Photographic studies	
		Drift bottle releases	
Nov. 29–Dec. 20, 1948	*Asterias*	Hydrographic Survey	
		Raritan & Lower Bay	83
June 17–July 5, 1949	*Asterias*	Hydrographic Survey	
		Raritan & Lower Bay	83
Aug. 16–23, 1949	*Caryn*	Hydrographic Survey	
		New York Bight	630
		Drift bottle releases	
Jan. 4–8, 1950	*Albatross III*	Hydrographic Survey	
		New York Bight	650
		Drift bottle releases	

The contribution of iron to the area at the time of seven cruises is shown in the second and third columns of Table 11. The rivers

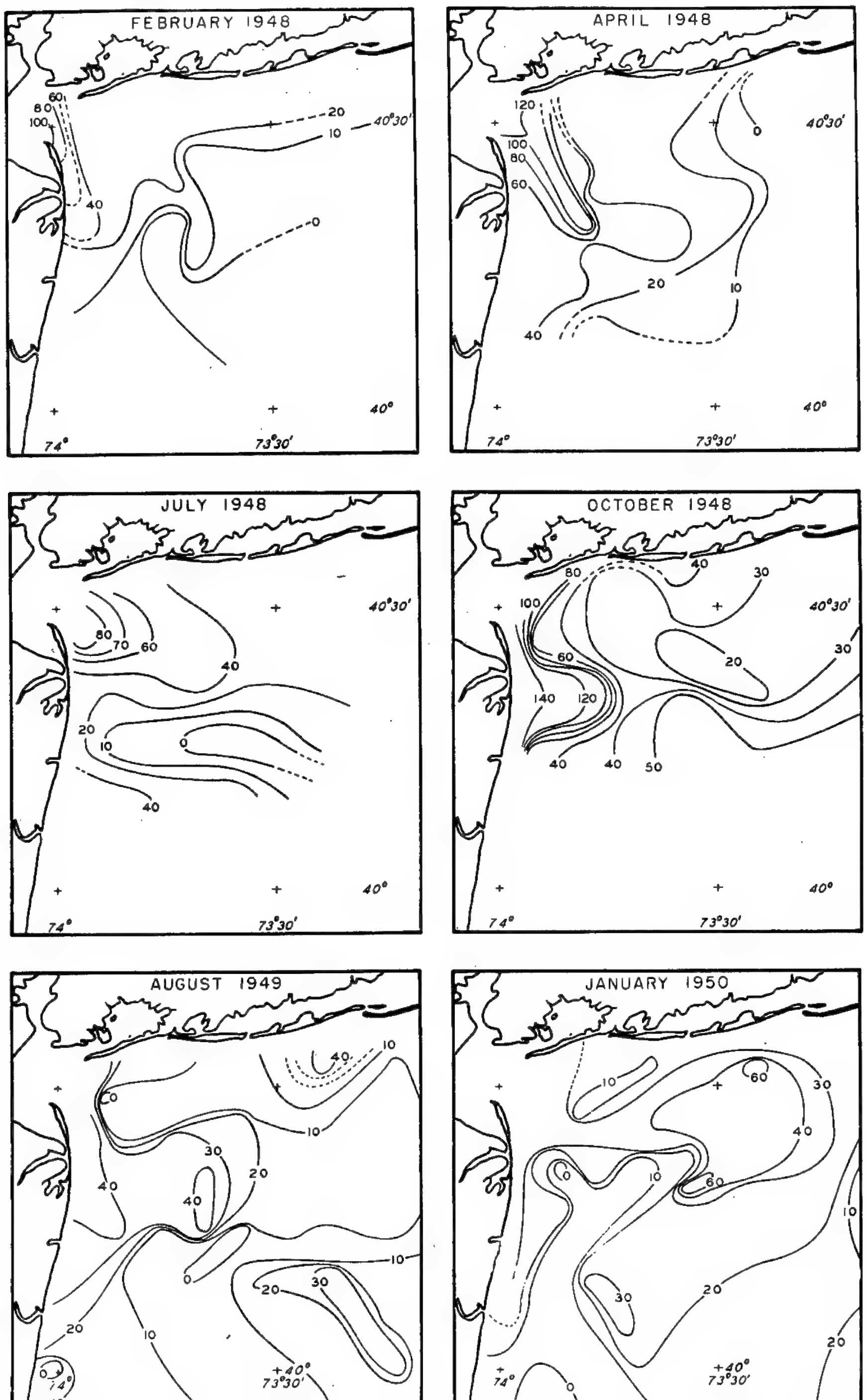


Figure 16. Distribution of iron in the surface waters of the New York Bight. Contours show iron concentrations in parts per billion (micrograms per liter).

contributed about 50 tons of iron daily in February, July, and October, 1948, and in January, 1950. In March and April, 1948, when the quantities were greater (159 and 112 tons per day) the river flow was exceptionally great (cf. Table 15). In August, 1949, when the river flow was very small, the contribution of iron was only 15 tons daily. As a general rule, the rivers are contributing about 50 tons of iron daily, a quantity approximately equal to the amount introduced by the barging operations. Prior to the barging operations, some one hundred tons of iron were being carried to sea past Sandy Hook each day; one-half derived from the river flow, one-half from the waste then being discharged into Raritan River. After barging began, only fifty tons passed Sandy Hook daily—all being of river origin. The effect of barging was thus to relieve the Raritan River and Bay of the extra load of pollution without altering the amount of iron which ultimately reached the sea.

The total quantity of iron in the water of the surveyed area was obtained from the sum of the iron content of small segments bounded by the lines of stations where samples were collected. The iron content of the water in each segment was estimated from the average quantity of iron under a unit area at the contiguous stations multiplied by the area of the segment. The total area surveyed during the various cruises and the quantity of iron accumulated are shown in Table 11.

Direct comparison of the quantity of iron within the area is difficult because the size of the surveyed area varied from cruise to cruise. Furthermore, the quantity present at any time is related both to the rate of supply and to the flushing rate, which is determined by the circulation of the water. The data show clearly, however, that the change in quantity is extremely small compared to the rate of supply. For example, between July, 1948, and August, 1949, about 40,000 tons of iron were added to the

TABLE 10

Average Concentrations of Iron Observed in Various Places during the New York Cruises

Location	Parts per Million							
	Feb. 1948	Mar. 1948	Apr. 1948	July 1948	Oct. 1948	Dec. 1948	June 1949	Aug. 1949
Head, Raritan Bay		4.0		4.0		3.0	0.15	
Off Coniskonk Pt.		1.57		0.3		0.25	0.03	
Off Pt. Comfort		0.70		0.29		0.10	0.10	
Inside Sandy Hook		0.24		0.17		0.03	0.10	
Sandy Hook	0.15			0.27				
Scotland Light	0.035	0.081	0.117	0.060	0.056			0.033
Ambrose Light	0.018	0.043	0.012	0.047	0.030			0.040
Shrewsbury Rock	0.034	0.045	0.044	0.015	0.134			0.034
Original Dumping Area	0.003	0.009	0.013	0.009	0.025			0.019
Cholera Bank	0.008		0.021	0.020	0.066			0.013

TABLE 11

Comparison of Iron Entering the New York Bight and the Quantity of Iron Accumulated within the Area

Date	River Contribution	Iron Dumped at Sea	Surveyed Area	Accumulation of Iron	
	tons per day	*tons per day*	*sq. mi.*	*tons*	*days*
Feb. 1948	52.5		483	552	10.5
Mar. 1948	159				
Apr. 1948	112		662	896	8.0
July 1948	51	60	684	1350	12.2
Oct. 1948	57.5	60	468	1436	12.2
Aug. 1949	15	80	630	1107	11.7
Jan. 1950	49.5	80	650	1807	13.9

water in this area. The quantity of iron within the surveyed area, however, showed virtually no change.

The most significant figures in the table are the number of days required to flush the iron through the surveyed area. The fact that the total quantity of iron within the surveyed area corresponds to from 8 to 14 times the daily contribution shows that there is no danger of substantial accumulation of iron within the area as a whole. A combination of a high rate of supply and a slow flushing rate will give a temporary accumulation, such as that observed in January, 1950. It is reassuring, however, that a period of two weeks or less is adequate to modify the accumulation when prevailing conditions change.

In contrast to the offshore areas, the iron content of the water in Raritan and Lower Bay has changed greatly following the initiation of barging. The results of three surveys of these bays are shown in Figure 17. In March, 1948, prior to barging, the water of the southern half of Raritan Bay contained in excess of 2000 parts per billion of iron. In contrast, in June 1949, fourteen months after the commencement of barging, there were present in the water not more than 150 parts per billion.

The facts relative to the distribution of iron are of interest because they illustrate a point frequently overlooked in the discussion of pollution problems. Many of the pollutants of rivers ultimately find their way to the sea. Procedures such as barging or the construction of sewers which carry these pollutants directly to sea may greatly improve conditions in the rivers and their estuaries without necessarily altering the conditions which exist at sea.

2. THE ACCUMULATION OF IRON AT THE BOTTOM

THE accumulation of waste materials on or near the bottom appears to have been considered likely when the original disposal area was selected, and led to the choice of a spot where unusual depths occur. This was natural when the high density of the waste was considered. The quantity of iron in the waste is such that if it were all deposited on the bottom as metal in the four square miles originally assigned for disposal, it would build up a layer less than one-half millimeter thick in one year. As iron oxide or hydroxide, the layer would be somewhat thicker. While the material deposited would not have poisonous properties, it was thought that it might alter the character of the bottom sufficiently to influence marine life and in particular the bottom fisheries.

The observations on the behavior of the waste when discharged from the barge showed very clearly that these fears are groundless, since the iron is precipitated in such a highly dispersed form that it does not sink rapidly and must be widely distributed before reaching the bottom. The failure of the surveys to show any accumulation of iron either at the surface or at greater depths supports the view that the precipitated iron is widely dispersed by currents before it settles. If this is the case, then it should make no difference whether the iron reached the area by barge or by the normal route down the rivers and bays.

Although the possibility of finding accumulations of iron compounds on the bottom seemed remote, samples of the bottom were collected in the area originally assigned for disposal prior to the beginning of these operations and on several occasions thereafter. The results of the iron analyses of the bottom sediments are given in Table 12. Some of the samples were obtained with a small "orange peel" dredge which scoops up a sample from the upper two or three inches of the bottom sediment. Other samples were taken in coring tubes, and for these samples the length of the core and the analysis of the upper and lower part of the core are given. It is interesting that the upper and lower part of the core samples showed substantially the same iron content. Although the age of these sediments has

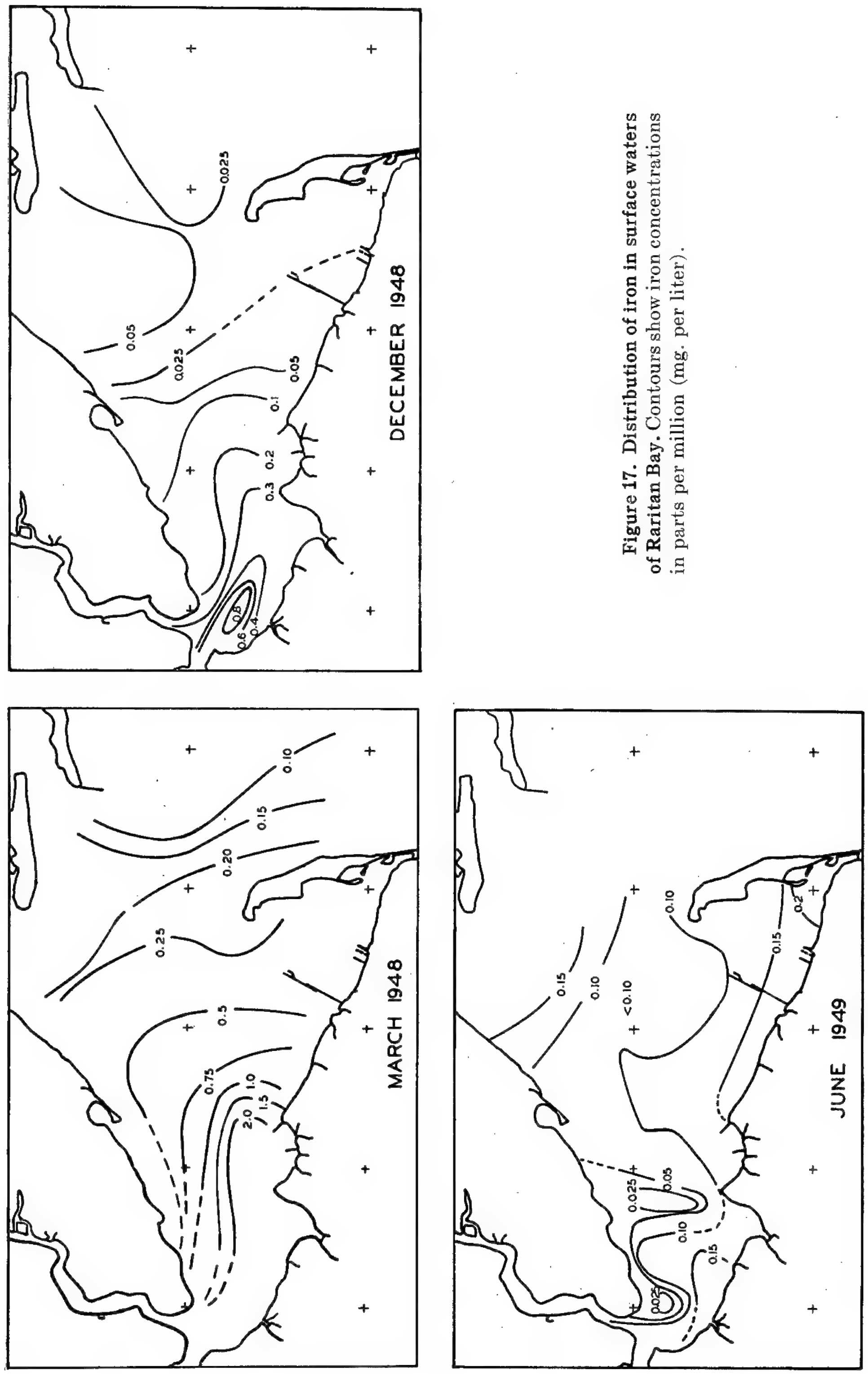


Figure 17. Distribution of iron in surface waters of Raritan Bay. Contours show iron concentrations in parts per million (mg. per liter).

not been determined it seems probable that it has taken centuries for them to accumulate to the depth of 10–20 centimeters. It appears, therefore, that the iron contributed during the last several decades as a result of the industrial development of the region has, as yet, had no measurable effect on the iron content of the bottom deposits.

TABLE 12

IRON CONTENT OF BOTTOM SAMPLES COLLECTED IN NEW YORK BIGHT

SAMPLED WITH ORANGE PEEL DREDGE

Date	Place	Iron Content
		mg. per gram
March 1948	Original Disposal Area	2.9
		5.0
		4.7
May 1948	Mud Hole	6.2
		9.5
Average		5.7

SAMPLED WITH CORING TUBE

Date	Place	Length of Core	Iron Content	
			Upper Part	Lower Part
		cm.	*mg. per gram*	
May 1948	Original Disposal Area	10.5	6.2	6.4
		16	7.3	5.8
		20	6.5	6.1
		12	6.1	6.2
		14.5	7.4	8.2
		14	5.3	6.4
		16.5	7.5	5.7
Average			6.6	6.4

3. THE TURBIDITY OF THE WATER

FISHING INTERESTS have expressed alarm that the turbidity of the water due to the presence of precipitated iron may prove distasteful to fishes, particularly the migratory pelagic species such as mackerel and tuna. The initial turbidity of the wake is certainly dense enough to give credence to this view. As was pointed out in the preceding section, the turbidity of the wake is dispersed rapidly and the affected water cannot be detected after about eight hours. It is possible, however, that the accumulation of ferric hydroxide over long periods might lead to a general loss in transparency of the water, which, while it could not be recognized by eye, might nevertheless affect fish directly, or indirectly through its effects on the microorganisms which supply their food. Consequently, a careful survey of transparency of the water of the offshore area was made during each cruise.

The transparency of sea water is measured very simply by lowering a white disk, known as a Secchi disk, over the side and noting the greatest depth at which it is visible. It is invariably found that transparency dedecreases as the shallow water along shore is approached. This is because of the presence of fine sediments stirred up from the bottom by tidal and wave action. Transparency will also reflect the abundance of microorganisms in the water, and also the presence of certain types of pollution.

The river effluent was always very turbid, and the Secchi disk was visible to depths varying from 3.5 to 0.75 meters at the entrance to Lower Bay. The offshore transparencies reflected primarily the distribution of this turbid river effluent. Water which was not appreciably diluted with the river effluent was clear and blue, and the disk could be seen at depths of 10–16 meters. The results of transparency measurements made in February, 1948, prior to the disposal operations, and in August, 1949, after sixteen months of barging, are shown in Figure 18. On these charts the contours indicate the greatest depth at which the Secchi disk could be seen. The survey in August 1949 showed no evidence of a decreased transparency in the neighborhood of the disposal area. The water in that region appeared beautifully clear and blue in contrast to the turbid green water found nearer to shore where most of the fishing boats were concentrated.

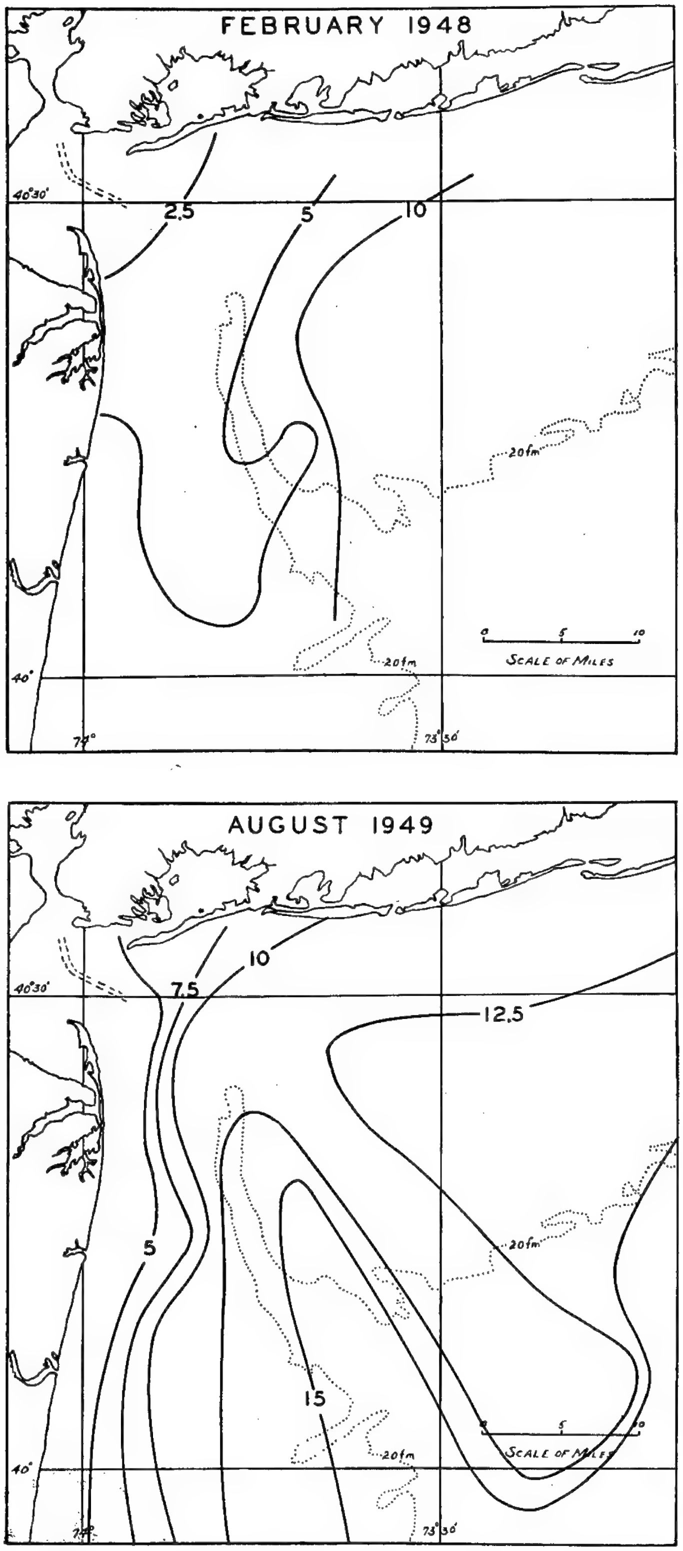


Figure 18. Transparency of the waters of the New York Bight in February, 1948, prior to disposal of titanium wastes offshore, and in August, 1949, after more than a year of disposal.

4. SUMMARY

CONCENTRATIONS of iron in the offshore area have not measurably increased since the disposal operations were started, but the concentrations of iron in the waters of Raritan Bay have decreased greatly. The principal objective of the operation, to decrease the pollution load in Raritan River and Bay, has thus been achieved without materially changing conditions at sea.

There has been no accumulation of iron in the water. The total quantity present corresponds to the amount of iron contributed by the river and barge in 8 to 14 days. About half of the iron entering the sea off New York is still supplied by the Hudson and other rivers draining into the area.

There has been no measurable accumulation of iron on the bottom in the area assigned for waste disposal.

There is no indication that accumulation of the wastes being barged to sea has altered the transparency of the offshore waters where disposal is in operation.

V. THE CIRCULATION OF WATER IN THE NEW YORK BIGHT[5]

1. THE NATURE OF WATER MOVEMENT

THE FATE of pollutants discharged at sea depends on the motion of the water. The character of this motion must be kept in mind in judging the effects of waste disposal operations and in attempting their regulation. Several types of motion may be distinguished:

Eddy motion. When water is acted on by any force, as by tides and winds, the imparted energy tends to be dissipated in the formation of eddies. These eddies vary greatly in size, and small eddies may revolve within larger ones. The total motion is consequently most difficult to measure or describe. The result of the eddy motion is to mix the water, and thus to lead to the greater dispersion of any pollutant both horizontally and in depth. It does not effectively carry the pollutant away from its source, except by gradual spreading in every direction.

Tidal Currents cause the water as a whole to move back and forth in a regular way, timed in the main by the rotation of the earth and the moon. In the open sea, the tidal currents change direction continually so that the drift of any particle is in a circle. The velocity of movement is not very great and the total excursion in a single tidal period is small. Along the shore, the circular motion is hindered by the shore and the course of drift becomes an ellipse. This is the condition found at Ambrose and Scotland Lightships. Within bays and channels, the elliptical character of the motion is entirely suppressed and the water moves back and forth in a direction which is reversed periodically.

[5] A discussion of the theoretical treatment of the results reported in this section and a more detailed presentation of the data may be found in a paper by Ketchum, Redfield and Ayers (**9**).

Tidal currents themselves do not cause the water to move permanently away from its original position. Their effect on the distribution and dispersion of pollutants is due to the mixing occasioned by the eddy motion which accompanies the flow of the tidal streams.

Non-Tidal Drift. The tidal currents which flow in opposite directions are rarely exactly equal because there are usually other forces acting on the water, such as hydrostatic gradients occasioned by river flow, forces due to the rotation of the earth, and the prevailing winds. Consequently, there is a net movement in certain general directions which has the effect of a current in carrying the water from one place to another. This movement cannot properly be called a current since it is not continuous in any one direction. It is referred to as the *non-tidal drift* and is usually small compared to the actual tidal excursion. Nevertheless, it is the effective agency for carrying pollutants away from the area into which they are discharged.

The non-tidal drift of the water can be measured directly only by anchoring a ship and making accurate measurements of the tidal currents over a period of several weeks. Scotland and Ambrose Lightships are the only places in the approaches to New York where such measurements have been made. Since the expense of securing adequate information by this method would be prohibitive, it is necessary to determine the character of the non-tidal drift by less direct methods. The procedure adopted was to examine carefully the distribution of salinity in the water and from this to attempt to infer the circulatory paths by means of which the fresh water of the Hudson River finds its way seaward, and the rates at which this transport takes place. Supplementary information was secured by the use of drift bottles.

2. SALINITY DISTRIBUTION

The coastal water lying between Cape Cod and Cape Hatteras has a salinity which varies in general between 30 and 33 parts per thousand, the lower values being found nearer shore. There is some seasonal variation dependent upon rainfall, spring freshets, etc. Only where the larger rivers exert their influence does the salinity fall below 30 parts per thousand (**2**). The Hudson, Raritan and other rivers of the New York area are separated from the sea by extensive bays and estuaries in which the fresh water of the rivers is mixed with the sea water. Thus, in the Raritan River, the principal zone of mixing occurs in the eight miles of tidal estuary lying above Perth Amboy. In issuing into the head of Raritan Bay, the water is already two-thirds salt (salinity about 20 parts per thousand). Similar conditions exist in the inner harbor of New York as the result of mixing in the lower Hudson River. In Raritan and Lower Bays the salinity varies between about 20 and 30 parts per thousand. The transition between the Bay water and the coastal water is usually fairly abrupt and is conveniently marked by the isohaline for 30 parts per thousand. The transition is the result of active mixing resulting from tidal currents in the shallow area lying at the mouth of the Lower Bay between Sandy Hook, Rockaway Point, and Scotland Lightship.

It is a well-established principle that off the mouth of a river two sorts of non-tidal drift will be established as a result of the flow of fresh water into the sea. First, to maintain the hydrostatic level the river water must be carried away as fast as it enters the sea. Second, since the river water mixes with progressively greater volumes of sea water as it moves seaward, there must be a counter-drift of salt water toward the estuary to provide this part of the mixture.

We may interpret tongues of fresher water extending seaward to represent the non-tidal drift away from the Lower Bay, and tongues of saltier water extending in from the sea, to represent the counter-drift of salt water needed to supply the mixture.

The distribution of salinity in the surface waters, which is illustrated in Figure 19, varies greatly from time to time. The most constant feature is the tendency of the less saline water to extend southward from Lower Bay along the New Jersey coast. This pattern was observed in February, 1948, October, 1948, August, 1949, and January, 1950. It indicates the principal course of the non-tidal drift in which river water is carried away from the entrance to New York Harbor at those times. However, in April and July, 1948, the pattern was quite different. At these times the less saline water spread widely to the eastward, particularly in the latter month. The freshened water was then separated from the coast of northern New Jersey by a tongue of water of higher salinity. This indicates that the southward drift along the coast was not present, and that it was replaced by a northward counter-drift, or by an upwelling of deeper water along the shore.

The distribution of salinity below the surface is also instructive. Figure 20 shows the vertical distribution in a section which extended eastward from Elberon, New Jersey, and thus passed through the disposal areas assigned to the National Lead Company. It may be seen that in February, 1948, October, 1948, and August, 1949, the salinity was fairly uniform from surface to bottom, with the freshest water occupying a deep tongue along the shore. In cont ast, in April, 1948, July, 1948, and January, 1950, when the less saline water was spread more widely to the eastward, it occupied a thin layer near the surface, under which layers of increasing salinity extended in the horizontal direction in a stratified pattern. The drift of freshened water at these times was evidently confined to a shallow layer moving seaward at the surface.

The sections also show that the most saline water observed was found in the

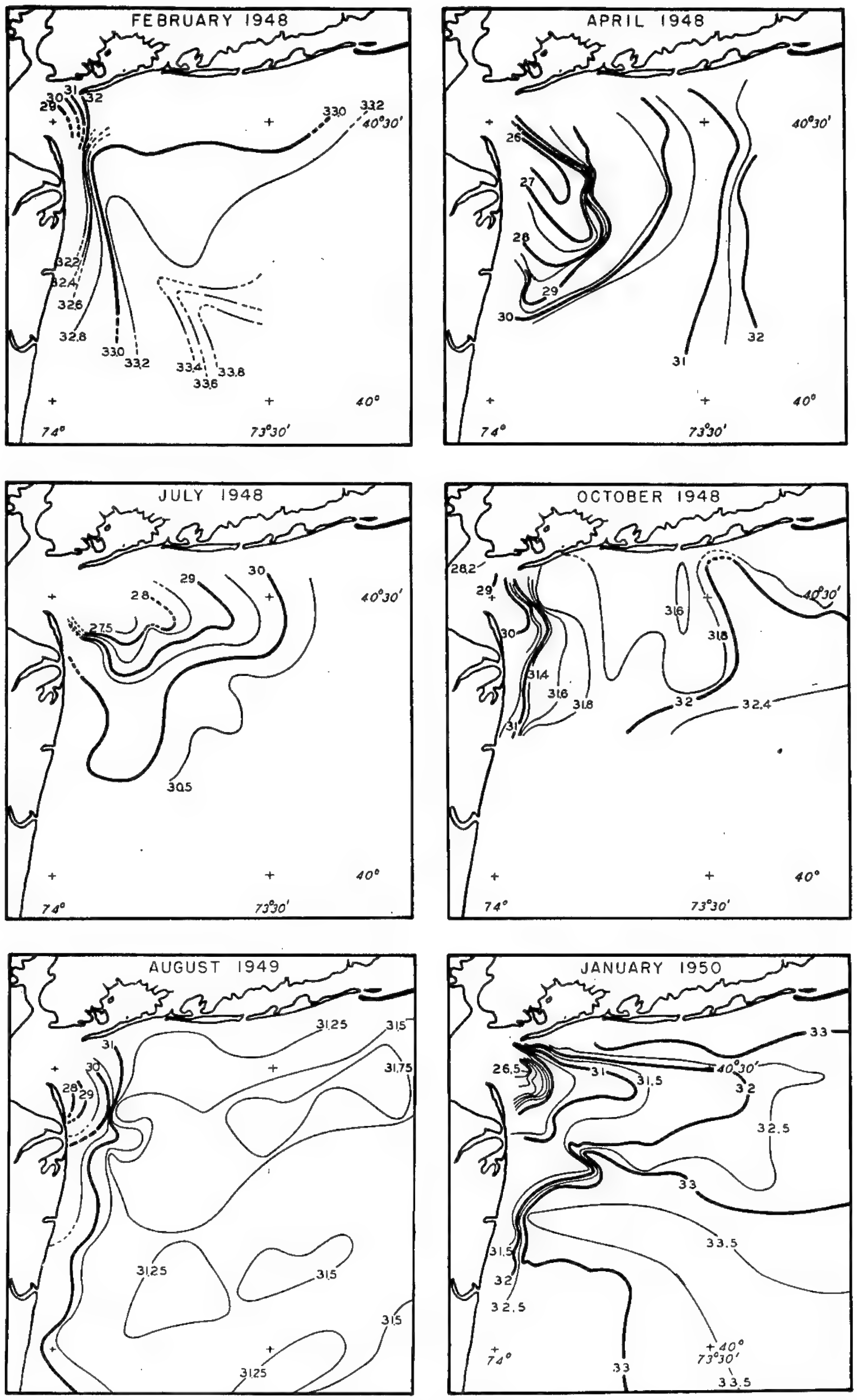


Figure 19. Distribution of salinity in the surface waters of the New York Bight. Contours show salinity in parts per thousand.

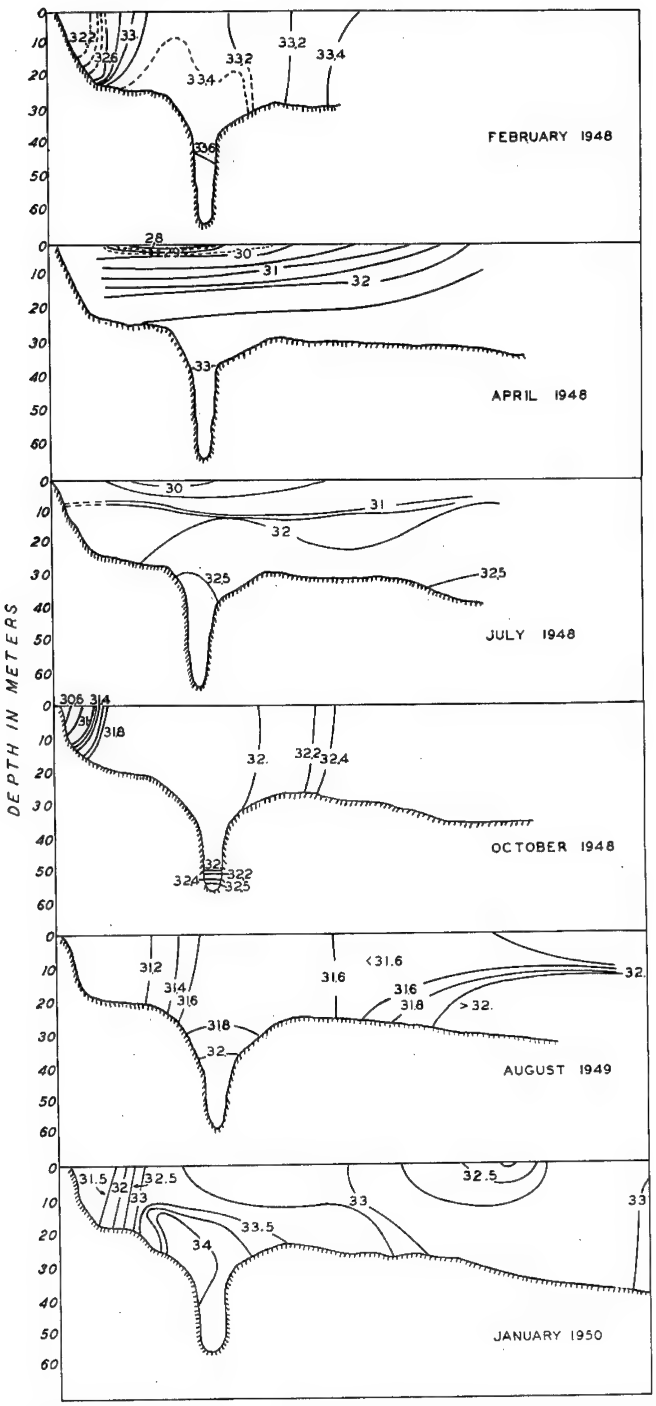


Figure 20. Distribution of salinity below the surface in a section extending eastward from Elberon, N. J. Contours show salinity in parts per thousand.

trough of the old Hudson Gorge. In February, 1948, and August, 1949, higher salinities were found above the Gorge than in the shallower regions on either side. This suggests that the Gorge is the site of a countercurrent moving landward which serves to supply salt water to mix with river water as it escapes from the Harbor. The surface salinity in February, 1948, indicates that, at that time, this movement above the Gorge extended to the surface.

A severe storm may completely obliterate the pattern of salinity distribution by mixing

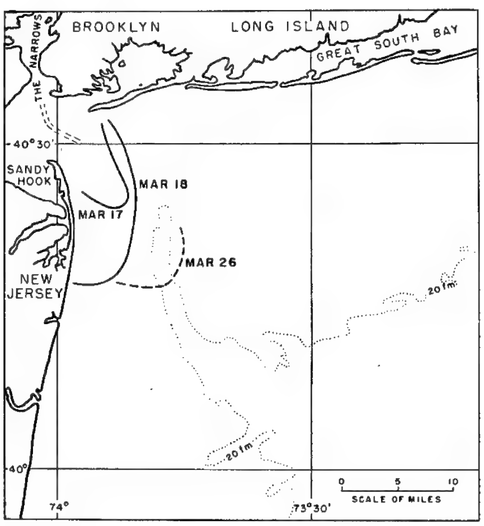


Figure 21. Changes in the location of the 30 parts-per-thousand isohaline following the storm of March 16, 1948.

the water from different areas and depths. This was observed to happen on March 16, 1948, when a southwest gale occurred. On the following day, the river effluent, characterized by salinities less than 30 parts per thousand, could be detected as a tongue extending seaward only four miles beyond Scotland Lightship. (See Figure 21.) By the following day, the tongue had advanced southward about eight miles to the offing of Long Beach, New Jersey. Eight days later this point still marked the southern extension of the tongue of river effluent, but it then extended widely to the eastward. Since the salinity pattern can have been reestablished only by some net drift of water, these observations give some indication of the rapidity of such movement.

To summarize, the effluent from Lower Bay tends to flow southward along the New Jersey coast in a tongue about five miles wide. A counter-drift appears to move in along the submerged Hudson Gorge to supply salt water to mix with the river effluent. Large eddies occur in the waters lying to the eastward of the coastal tongue of river effluent, and these probably serve to supplement the countercurrent in drawing salt water in to mix with the river effluent, as well as to spread some of the effluent to the eastward. This pattern of circulation was observed during three of the six periods of survey. At three other periods, in contrast, the southward movement of the river effluent along the New Jersey coast appeared to have been checked. Instead, the effluent was spread widely across the bight, and in two cases was separated from the New Jersey shore by more saline water. When these conditions occurred, the fresher water was confined to the surface layer as though it were flowing out over the deeper layers of the more saline coastal water. The counter-drift must lie in these deeper layers. The volume of the effluent is sufficiently large so that the pattern is reestablished rapidly after being disturbed by a storm, and presumably it can change with equal rapidity when the determining conditions are altered.

3. FACTORS INFLUENCING THE PATTERN OF CIRCULATION

THE SIX surveys which have been made are sufficient to show that the pattern of circulation is subject to variation between two widely different extremes. The earlier surveys suggested that these extremes might be related to the season, but as additional information accumulated it became apparent that this is not so, as may be seen by comparing the salinity patterns observed in

July, 1948, and August, 1949. It has become apparent that several variable factors are interacting to determine the actual character of the circulation at any one time. While the principal forces at work are evident and the nature of their influence may be stated, it is not possible to estimate their influence quantitatively in order to predict the outcome when they are in conflict.

The factors considered to influence the circulation in the New York Bight are the following:

1. The force due to the rotation of the earth, the so-called Coriolis force. In the northern hemisphere, this force causes moving water to turn to the right. Its effect is always present and locally is proportional to the velocity of the movement. It appears to be the factor responsible for the tendency of the river effluent to hug the New Jersey shore except when its influence is overbalanced by the other, more variable factors.

2. Hydrostatic forces arising from horizontal pressure gradients due to differences in temperature and salinity of the water.

   a. Hydrostatic forces arising from differences in the salinity of the water are due to the local decrease in density which results from the dilution of sea water by the river effluent. The forces increase with the volume of river flow and tend to cause the effluent to spread more actively following periods of heavy run-off.

   b. Hydrostatic forces arising from differences in the temperature of the water. These differences arise chiefly from the warming of the sea surface in summer, which reduces the density of the surface layers. These forces tend to confine the spreading effluent to the upper layers and may facilitate its spread. Their effect is seasonal.

3. Forces due to the wind. The wind causes the surface water to drift at an angle to the wind direction. Theoretically the motion at the surface is at an angle of 45° to the right of the wind direction. The detailed facts, however, are uncertain, particularly as they apply to shallow water and to variable winds of short duration. Prevailing winds from northwest to northeast may be expected to assist in confining the river effluent to the New Jersey shore. Prevailing winds from south through west will increase the tendency of the effluent to spread eastward. However, the influence of wind strength and duration cannot be stated quantitatively.

In the open ocean, where conditions exist in a steady state over long periods of time, it is possible to estimate the drift of the water on the assumption that the hydrostatic forces which result from the horizontal pressure gradients are exactly balanced by the Coriolis force due to the earth's rotation. In coastal waters the patterns of distribution are constantly changing, so that steady-state distribution cannot be assumed. It is possible to calculate the currents which would be required to maintain any observed set of conditions, but one cannot be assured that such currents actually exist since the estimate will be too large at times when the freshened water is tending to spread more widely, and too small when the reverse is taking place. If independent measurements of the currents can be obtained, it is possible to determine whether the observed conditions are stable (as indicated by their agreement with the estimates based on horizontal pressure gradients) or are in the process of change.

Estimates of the current flowing southward between Scotland Lightship and the coast at Sandy Hook have been made for each period of survey.[6] The results, entered in Table 13, may be compared with the observed non-tidal drift recorded at Scotland Lightship by the U. S. Coast and Geodetic Survey. The latter figures are based on long series of observations made throughout the year and reflect the average movement to be expected.

The comparison shows that at three

[6] For detailed discussion of the theoretical treatment see Ketchum, Redfield and Ayres (**9**).

periods, February, July and January, the current velocities calculated from the horizontal pressure gradient agree closely with the average conditions, and it may be assumed that the conditions observed at those times were stable. During the other three periods, the estimated current velocities greatly exceed the average observations, and the conditions appear to be dynamically unstable, and the deduced tendency to change would be toward more widespread distribution of the freshened water.

Two factors which must influence the development of the current pattern and

TABLE 13

CALCULATED CURRENT VELOCITIES BETWEEN SCOTLAND LIGHTSHIP AND SANDY HOOK AND OBSERVED AVERAGE NON-TIDAL DRIFTS RECORDED AT SCOTLAND LIGHTSHIP

Date	Calculated Current Velocities	Average Non-Tidal Drift	Deduced Dynamic State
	cm. per sec.	*cm. per sec.*	
Feb. 1948......	10.5	9.25	Stable
Apr. 1948......	21.7	9.25	Unstable—spreading
July 1948.......	7.8	9.50	Stable
Oct. 1948.......	23.1	9.50	Unstable—spreading
Aug. 1949......	66.2	9.50	Unstable—spreading
Jan. 1950.......	10.1	9.50	Stable

the resulting variation in distribution of salinity are the run-off from the rivers and the wind.

River flow data for the period under consideration have been provided by the offices of the U. S. Geological Survey in Albany, New York, and Trenton, New Jersey. The average monthly flow for the rivers tributary to Lower Bay are shown in Figure 22, while the average daily flow for the period of thirty days immediately preceding each survey is given in Table 14. It is evident that the quantity of fresh water entering the Bight varies greatly from time to time.

As the river flow increases, greater volumes of river water must be transported

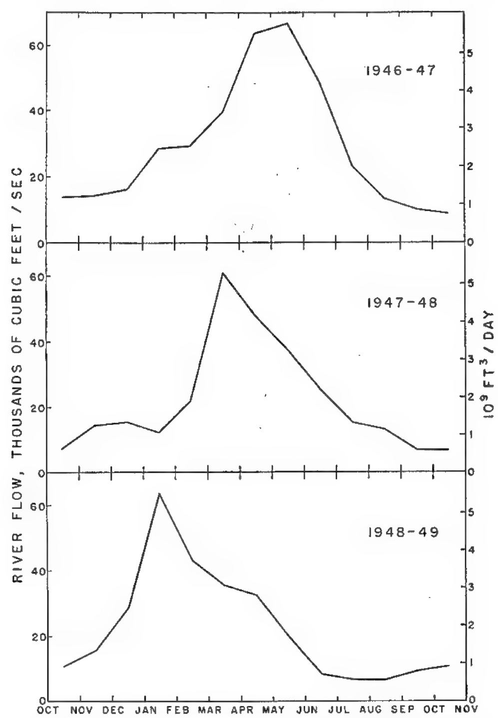


Figure 22. Daily river flow, averaged by months, of the Hudson and other river sources discharging into the New York Bight between Sandy Hook and Far Rockaway.

TABLE 14

AVERAGE DAILY RIVER FLOW AND PREVAILING WINDS DURING PERIODS OF SURVEY

Date	River Flow*	Mean Hourly Wind Velocity	Direction	Drift
	10^9 cu. ft. per day	*mi. per hr.*		
Feb. 1948.......	1.49	14.2	N	W
Apr. 1948.......	4.1	14.9	NW	W
July 1948.......	1.3	11.5	SW	E
Oct. 1948.......	0.6	13.5	N	W
Aug. 1949.......	0.6	8.8	SSE	E
Jan. 1950.......	2.63	12.2	NE	

* Mean daily flow estimated for thirty days preceding the dates of survey.

through the area in a unit period of time. This could be accomplished either by an increase in the velocity of the non-tidal

drift, or by an increase of the proportion of river water in the mixture moving seaward. The data show that the latter occurs, and that the velocities of non-tidal drifts remain substantially the same regardless of river flow.

As indicated by Table 13 the distributions observed during three of the cruises were dynamically stable. Apparently these patterns of distribution were primarily determined by the horizontal pressure gradients and Coriolis force. The calculated velocity in April, 1948, would transport about 70 percent of the river water southward along the New Jersey shore. It is possible that, at this time, the velocity of non-tidal drift was greater than the average velocity used for comparison in Table 13. The remaining two cruises were unstable, and the velocities required to produce stability would remove more fresh water than was contributed by the rivers. It may be significant that the river flow during these two cruises was appreciably lower than that observed during any of the other cruises.

Data on the prevailing winds during the several periods of survey are shown in Table 14. The effects of the wind cannot be evaluated quantitatively, but a qualitative summary may be useful in interpreting their contribution to the distribution patterns.

The winds during February and July, 1948, when stable distributions were observed, would tend to produce similar patterns. In January, 1950, the winds, though light, opposed the observed widespread, stable pattern in the northern part of the area.

In April, 1948, when it appeared possible that the non-tidal drifts were flowing southward with a greater than average velocity, the wind would be expected to augment this current along the New Jersey Coast.

In October, 1948, the northerly winds would augment the currents along the New Jersey shore, and thus tend to produce the unstable distribution observed at that time. The winds during the early part of this cruise were strong, which would increase the importance of the wind effect.

The winds, however, do not help to interpret the August, 1949, distribution pattern. The SSE winds at this time would produce a surface current in a general northeasterly direction. The observed pattern was unstable and the winds would augment the tendency for the freshened water to spread over the surface to the eastward.

It appears, therefore, that the three stable distribution patterns are primarily determined by oceanographic factors, and two of the unstable distributions can be qualitatively explained as a combination of oceanographic and wind effects. The August, 1949, distribution, however, was dynamically unstable, and was subjected to a wind which increased the instability. Presumably this pattern was transitory, and might be expected to change rapidly. More information on the effects of winds in producing currents in coastal waters is urgently needed to aid in interpreting the circulation and distribution of properties in localities such as the New York Bight.

4. THE RATE OF TRANSPORT OF FRESH WATER THROUGH THE AREA

THE accumulation of pollutants in any area into which they are discharged will depend upon the rate at which the water within the area is replaced as a result of the circulation. Although the pattern of circulation has proved to be variable, and as yet unpredictable in its details, it is possible to reach some general conclusions regarding the rate at which water is moving through the New York Bight. These are the most useful results of the survey.

The method of investigation depends upon the use of the fresh water entering from the Hudson and other rivers as a tracer. The results obtained should apply to any pollutant carried in solution or fine suspension.

In the case of a river, the average velocity with which the fresh water is moving is

given by dividing the flow through a cross section of the channel by the area of that cross section. Where the river enters the sea, a large quantity of salt water is mixed with the fresh water and moves with it. In order to estimate the velocity of movement of fresh water across any section drawn from shore to shore, it is necessary to estimate the fraction of the section which is occupied by fresh water. The area of this fraction of the section is then divided into the river flow to obtain the average velocity of drift of the fresh water seaward.

The fraction of the section occupied by fresh water can be estimated from the average salinity of the water in the section, provided it can be assumed that this water is a simple mixture of river water and sea water of some known source and composition. It is difficult to determine the salinity which should be ascribed to the sea water entering the New York Bight for purposes of calculation, and the value chosen may have a large effect on the result of the estimate.

In the present calculation we have chosen the salinity observed at a station about 25 miles east of Sandy Hook and 10 miles south of the Long Island shore. This water was similar to water extending eastward off the Long Island coast. Since the general drift is westward along this shore, similar water would be expected to occupy the area of survey if the flow of fresh water from the Hudson did not exist.

Estimates have been made of the seaward movement of fresh water across four sections extending from the New Jersey to the Long Island shores, as shown in Figure 23. The results are shown in Table 15. These estimates bring out two points of interest.

1. The velocity of seaward drift varies from about one to six miles per day and has an average value for all times and sections slightly less than three miles per day (1 nautical mile = 6080 feet). This is the average rate at which pollutants may be expected to be carried seaward.

2. The drift across the various sections is about equal in rate, and is not evidently correlated either with the size of the river flow or the distance from the river mouth. This observation indicates that the rate of movement of pollutants through the area is determined by the general circulation of the ocean water (tidal movements and non-tidal currents) rather than by the conditions of flow in the rivers.

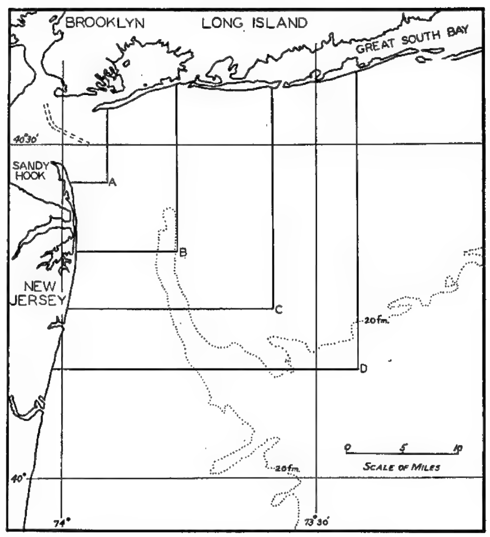


Figure 23. Diagram showing position of sections across which average seaward drift of river water has been calculated.

5. THE FLUSHING TIME

THE average time required for a particle of fresh water discharged into an area by rivers to be carried out of the area is called the flushing time. It may be estimated by dividing the volume of fresh water in the area by the daily river flow. In the case of the area off the mouth of the Hudson River, the flushing time has been estimated by integrating the fresh water content at the points of observation throughout the area and dividing this value by the recorded river flows. The results of these estimates are given in Table 16. They show that the fresh water, on the average, moves out of the area in six to ten days.

This result should apply to any pollutant dissolved in the water or carried as a fine suspension. Observations on the iron content of the water in the area and estimates of the rate at which iron is entering from the rivers or from barging operations have been used to check this conclusion.

Table 16 shows the flushing time of the area estimated from data on iron. The results so obtained vary from about 8 to 14 days. They are thus in substantial agreement with those obtained from the fresh water transport, though in every case somewhat longer flushing times were obtained.[7]

A further check on the rate of transport of water through the New York Bight is provided by data obtained by the recovery of drift bottles along the shores. During the surveys of July and October, 1948, and of August, 1949, and January, 1950, more than 2,000 drift bottles were dropped overboard at points uniformly distributed throughout the area. (See Table 17.) At other times additional bottles were released in the original waste disposal areas from the barge operated by the National Lead Company, and from the U. S. Fish and Wildlife Services vessel when she visited the region. Reports have been received of the recovery of 13 percent of these bottles, of which 5.4 percent were found on the Long Island shore, 6 percent on the New Jersey coast, and 1.6 percent on the coast between Cape May and Cape Hatteras. Five bottles have been found which have made long oceanic traverses to Bermuda, the Azores, Ireland, and Portugal.

From the time elapsing between release

TABLE 15

AVERAGE SEAWARD DRIFT OF FRESH WATER ACROSS VARIOUS SECTIONS OF THE NEW YORK BIGHT

Date	River Flow	Drift in Feet per Day Across Section			
		A	*B*	*C*	*D*
	$10^9 ft^3/day$				
Feb. 1948	1.49	26,700	20,500	13,400	9,100
Apr. 1948	4.1	19,800	17,900	17,300	23,100
July 1948	1.3	14,700	12,000	15,800	20,500
Oct. 1948	0.6	12,600	7,930	13,800	
Aug. 1949	0.6	6,210	38,400	11,600	27,400
Jan. 1950	2.63	19,500	18,100	24,200	17,400

TABLE 16

ESTIMATES OF THE FLUSHING TIME FOR THE AREA OFF THE MOUTH OF THE HUDSON RIVER, BASED ON FRESH WATER TRANSPORT

Date of Survey	Area Surveyed	Contained Volume		River Flow	Flushing Time*	
		Total	River Water		River Water	Iron
	sq. mi.	*10^9 cu. ft.*	*10^9 cu. ft.*	*10^9 cu. ft. per day*	*days*	*days*
Feb. 1948	483	1399	8.92	1.49	6.0	10.5
Apr. 1948	662	1987	30.41	4.09	7.5	8.0
July 1948	684	1945	12.66	1.30	9.7	12.2
Oct. 1948	468	1259	6.34	0.60	10.6	12.2
Aug. 1949	630	1830	3.63	0.46	7.9	11.7
Jan. 1950	650	1895	15.69	2.51	6.3	13.9

* See Table 11.

[7] The possible causes of this difference in the flushing times based on fresh water and on iron are discussed by Ketchum, Redfield and Ayers (**9**).

and recovery some idea can be obtained of the rate of drift. The data for recoveries from the Long Island and New Jersey coasts were analyzed to show the number of recoveries during successive five-day periods from the different parts of the coast. The results are presented in Figures 24 and 25. It may be seen that in the sections of coast within thirty miles of the entrance to New York Harbor—that is, between Fire Island Inlet and the head of Barnegat Bay—very few bottles were recovered more than ten or fifteen days after release. At greater distances the time elapsing between release and recovery increases, as is to be expected.

TABLE 17

SUMMARY OF THE DATA ON DRIFT BOTTLES RELEASED IN THE NEW YORK BIGHT

Date of Release	Number of Release Points	Number Released	Number Recovered	Percent Recovery
July 27, 28, 1948	16	240	27	11
Oct. 22–27, 1948	14	210	30	14
Nov. 1, 1948	3	54	12	22
Jan. 24, 1949	1	100	2	2
Feb. 10, 1949	1	40	0	0
Feb. 21, 1949	1	40	1	3
Mar. 9, 1949	1	40	10	25
Aug. 18–21, 1949	57	912	177	19
Jan. 5–8, 1950	37	592	24	4
Total	131	2,228	283	13

Since relatively few bottles were recovered from the shores immediately adjacent to the surveyed area after more than ten or fifteen days, the conclusion may be drawn that after that time most of the bottles had been carried out of the area. This is consistent with the estimates of the flushing time based on the transport of fresh water and of iron.

6. THE DRIFT OF THE SURFACE LAYER

THE SURFACE layer of the ocean is exposed directly to the action of the wind, and its motions do not necessarily coincide exactly with the mass movement of the underlying water. Drift bottles are carried about by the motion of the surface layer and give an indication of the probable transport of such pollutants as oil, garbage, and the floating solids derived from domestic sewage which may contaminate the water and find their way to beaches. The data obtained from the recovery of drift bottles consequently provide valuable information on the probability that floating pollutants released in any part of the area will reach the adjacent shores. The results cannot properly be applied to soluble or suspended pollutants since they take no account of dilution, which rapidly decreases the concentration of such contaminants in the course of their drift.

The data have been analyzed by dividing the bight into small areas ten minutes of latitude and longitude on a side. (See Figure 26.) For each area the number of bottles released was determined and the number of these recovered from the shores of Long Island or New Jersey expressed as a percentage. Smoothed contours were then drawn which express the percentage of bottles released in the different parts of the area which were eventually found on the beaches. These contours indicate the relative likelihood that floating objects present in any part of the area will eventually reach the shores.

Figure 27 gives the over-all picture, in which no account is taken of the place of recovery. As may be expected, the chance of recovery from the beaches decreases rapidly with distance from shore. From a distance of 10 miles from shore, an average of only 15 percent of the bottles reaches the beaches. From a distance of 20 miles off the coast, practically no bottles were returned. In Figures 28 and 29 the percentages of bottles reaching the coasts of Long Island and New Jersey from different parts of the area are shown. It is notable that very high percentages of returns were obtained from positions off the Long Island shore as compared with New Jersey. These returns came, however, from bottles released within five miles of the coast during the survey of August,

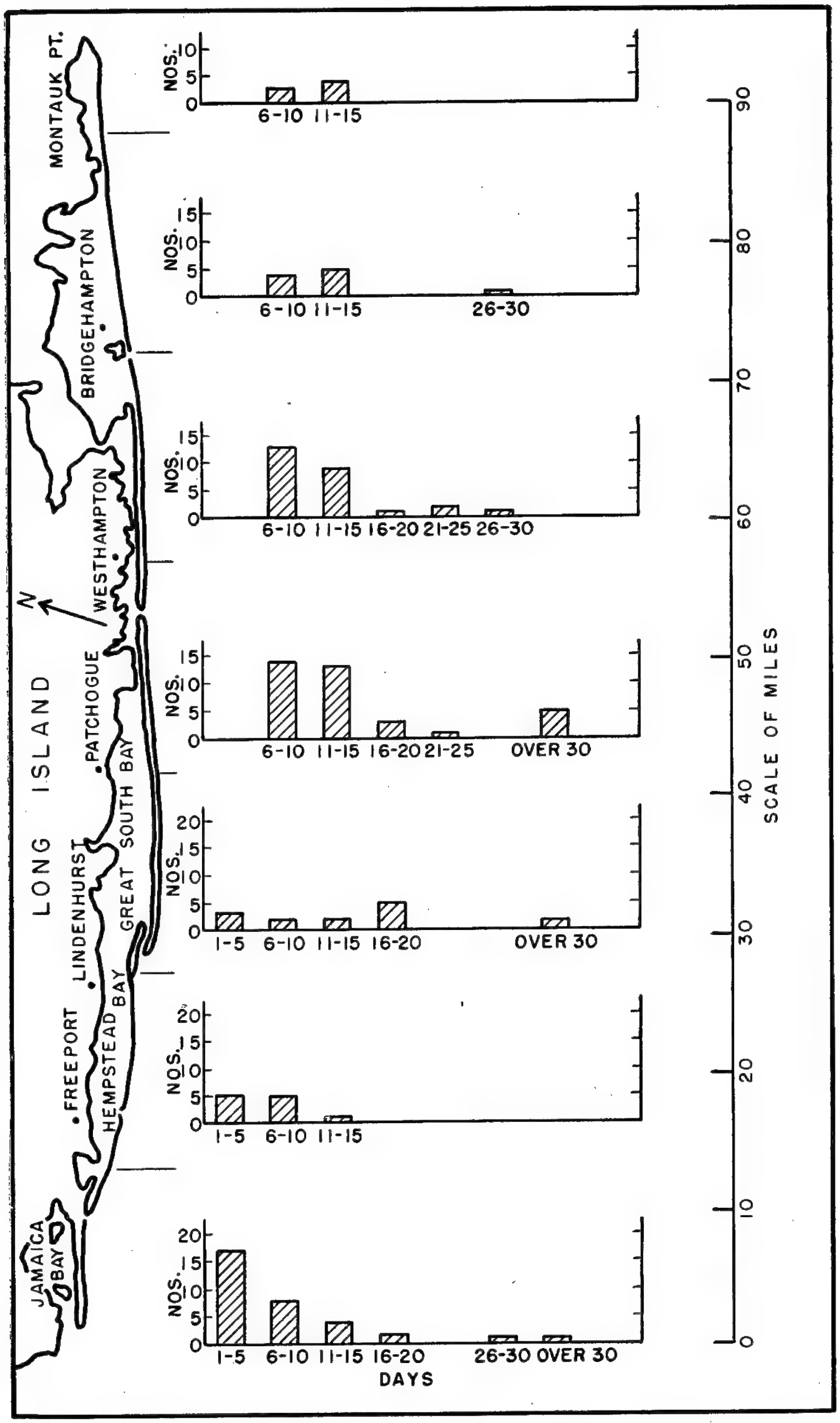


Figure 24. Numbers of drift bottles recovered from different sections of the Long Island coast during successive 5-day periods following time of release.

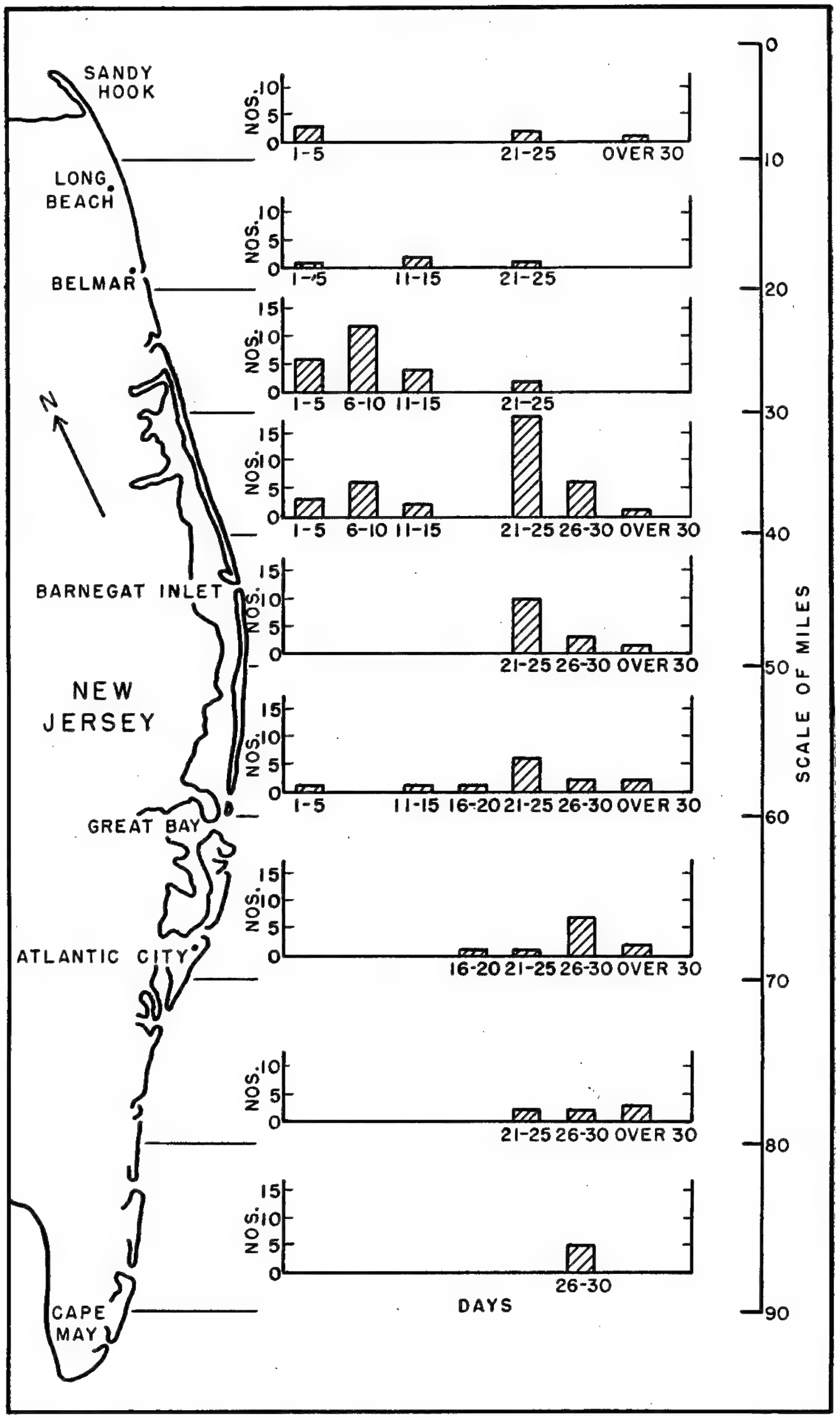


Figure 25. Numbers of drift bottles recovered from different sections of the New Jersey coast during successive 5-day periods following time of release.

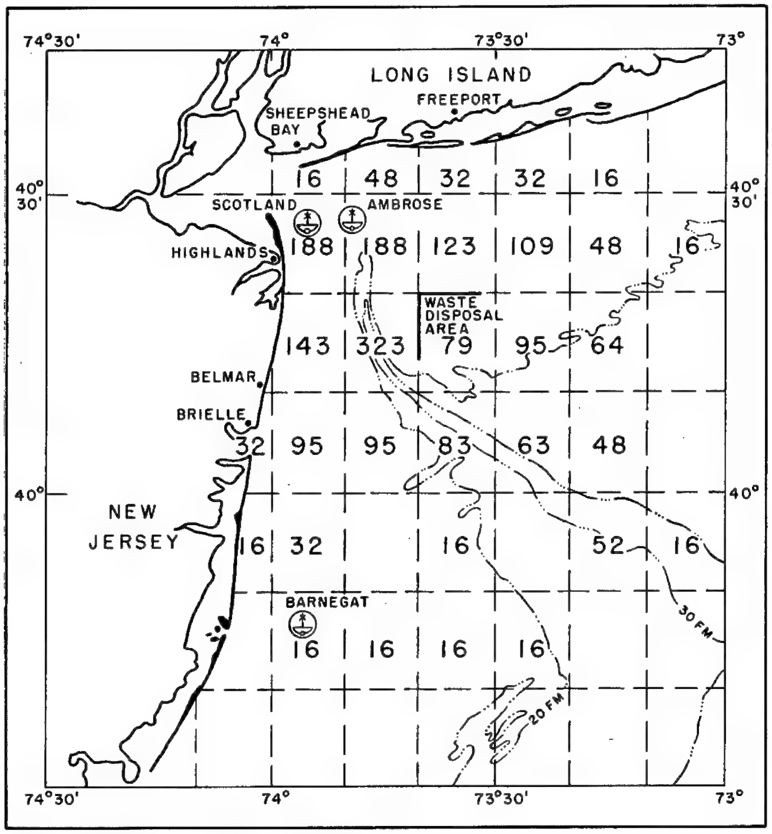


Figure 26. Chart showing rectangular areas used in analyzing drift bottle recoveries. The numbers indicate the number of bottles released in each area.

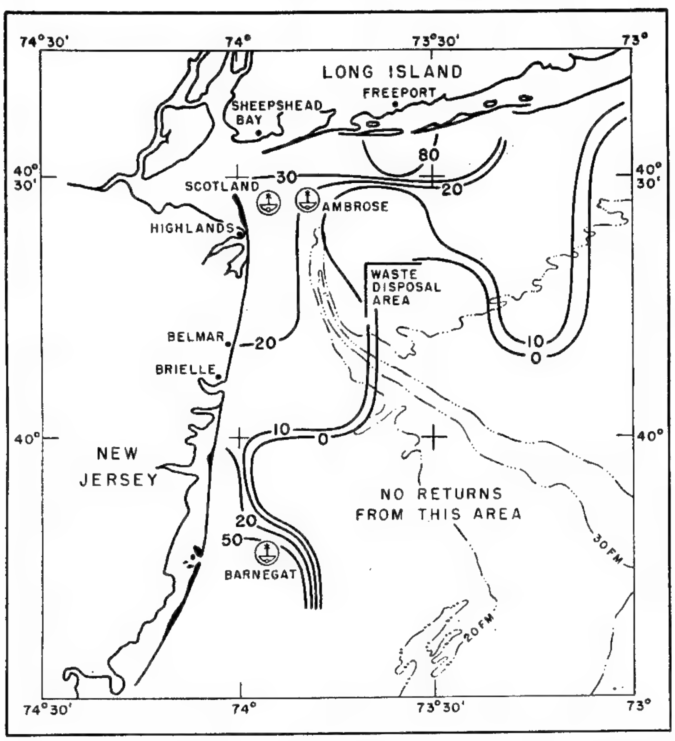
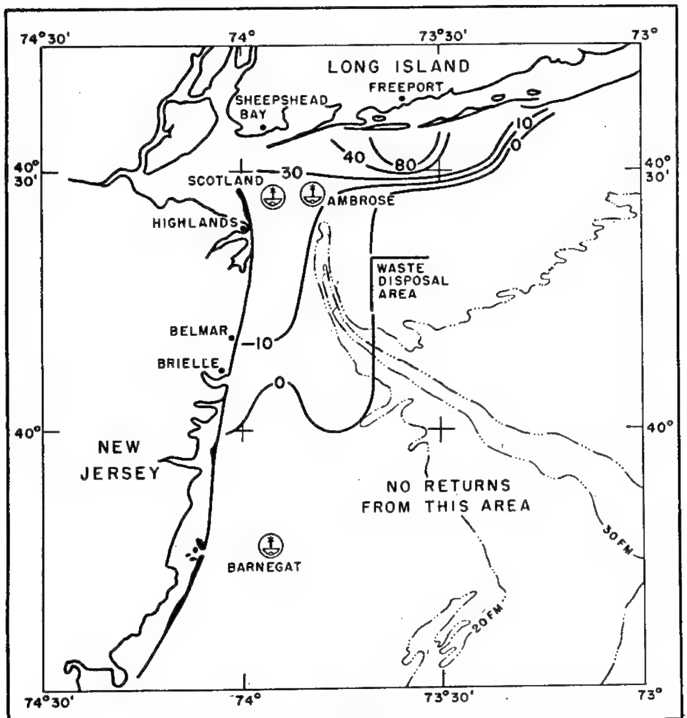


Figure 27. Chart showing percent of drift bottles released in various parts of New York Bight which were recovered anywhere on the coasts of Long Island and New Jersey.



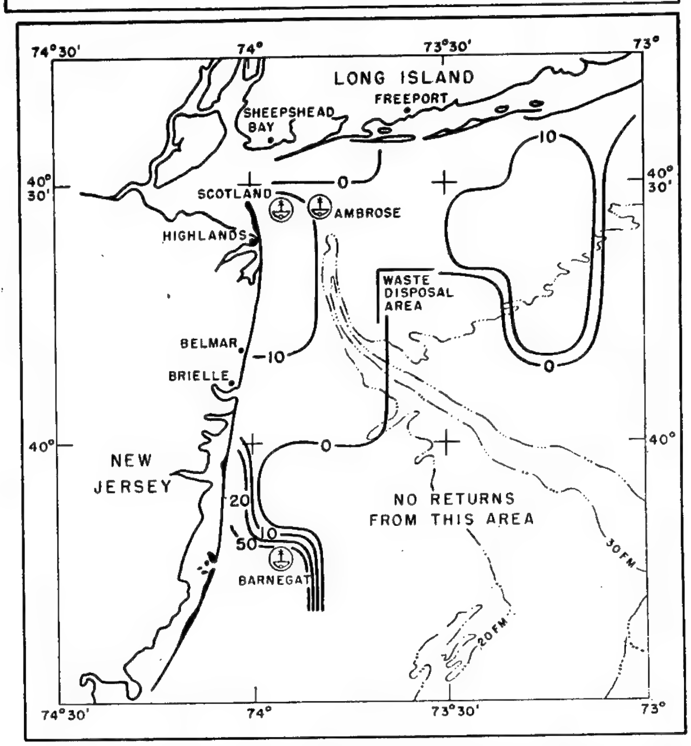


Chart showing percent of drift bottles released in various parts of the New York Bight which were recovered anywhere on the coast of Long Island (Figure 28, top) or New Jersey (Figure 29).

1949, when a somewhat unusual pattern of circulation was present.

The conclusion to be drawn from the drift bottle studies is that wastes likely to be transported to beaches in the surface layers should be carried at least ten miles to sea if contamination of beaches is to be avoided. While the wastes of the National Lead Company do not contain materials of this character it may be noted that the present disposal area appears to be well located, since less than ten percent of the bottles released there were recovered from the Long Island and New Jersey beaches.

7. SUMMARY

THE circulation patterns are quite variable, ranging from the most common type, which indicates that the river effluent escapes in a narrow band along the New Jersey coast, to one in which the river effluent is distributed widely over the surface of the area. Although five of the six distributions observed can be accounted for by the associated oceanographic forces and the winds, so many variables contribute to the circulation that predictions are not feasible. It would not be practical, for example, to select different disposal areas for different seasons of the year.

The fresh water from the rivers moves seaward across the area immediately off New York at an average rate of about three miles per day. Pollutants discharged into this water would be carried seaward at the same average rate.

Considering the area extending south and east about 25 miles from the shores, it is estimated that about ten days is required on the average for the replacement of the contained water by other water from outside the area. This result is confirmed by measurements of the accumulation of iron in the area and by the recoveries of drift bottles. It indicates that the accumulation of soluble and suspended wastes discharged into the area will be very limited.

The recovery of drift bottles indicates that the likelihood of floating materials reaching the adjacent shores decreases rapidly with their distance from shore, and becomes small at distances of ten miles or more.

VI. CONCLUSIONS

In attempting to evaluate the consequences of disposing of wastes in the offshore waters of the sea it should be emphasized that each type of waste presents an individual problem. The behavior of the waste will depend on its physical state, solubility, specific gravity, stability, and specific chemical and biological properties. It is evident, for example, that entirely different considerations are involved depending on whether the material sinks and accumulates on the bottom, dissolves and becomes dispersed in the flowing masses of water, or floats on the surface until cast up on the beach. A floating material like oil, which forms a coherent patch on the sea surface and results in a persistent nuisance when cast on the beach, presents a different problem from floating garbage, which may be widely dispersed by currents and decomposes rapidly after reaching the shore. Thus the results of the present study, while yielding information which should be of value in considering other problems, should be applied to such problems with caution and with due regard to the similarities and differences in the properties of the substances to be disposed of.

The acid ferrous sulfate waste from the titanium plant of the National Lead Company reacts rapidly with sea water to form inert materials which remain in solution, or to form extremely fine suspensions which are carried by the water movements for great distances before settling to the bottom. It has been found that the mixing and reaction of the waste with sea water take place rapidly in the wake of the barge. In consequence a relatively small volume of water is exposed temporarily to the harmful effects arising from the original acidity of the waste material. No evidence of the accumulation of products derived from the waste has yet been found. Consideration of the general rate of exchange of water between the New York Bight and the adjacent parts of the ocean makes it extremely unlikely that the quantity of waste discharged during more than a few days could be found in the region at any one time. No evidence has appeared which indicates that undesirable effects of any sort have arisen from these waste disposal operations.

In view of the above considerations, it is concluded that on its present scale the procedure employed by the National Lead Company in disposing of the wastes from its titanium plant is entirely proper. The operations should not be discouraged unless some new facts justify a contrary opinion.

The area presently assigned for disposing of the titanium plant's waste appears to be well chosen. It is sufficiently far from any shore to remove the possibility of contaminated water reaching the coast until greatly diluted. It is removed from the areas most frequented by fishermen. It is, nevertheless, sufficiently accessible from Lower Bay. It might be argued from the demonstrated facts that the harmful effects of the pollution are so slight and so well localized that the assignment of an area closer to the Bay would be proper. However, the imponderable factors are sufficiently great that it is prudent to continue operations at the present site.

In the consideration of the general problem of disposing of industrial or other wastes at sea, the most important result of the present investigations has been the demonstration of the rapid rates of exchange of coastal waters with adjacent parts of the sea. Judgments adverse to the use of the sea as a means of waste disposal are apt to be prejudiced by observations on the pollution of confined embayments where the exchanges of water are greatly reduced. Prejudice also exists because of the very undesirable pollution of beaches which fol-

lows the discharge at sea of floating wastes such as oil or garbage. The capacity of offshore waters to receive and disperse soluble or suspended wastes without undesirable effects is very large and might properly be used more extensively. Each proposed operation, however, should be examined critically to make sure that the waste is of a character to be safely treated as proposed, and that the disposal site is properly chosen in relation to the local hydrography, the disposition of fishing grounds, and the presence of other interests which might be adversely affected.

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